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AN ASSESSMENT AND DESCRIPTION OF THE STATUS OF BOTTOM FISH STOCKS IN HAWAII

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ABSTRACT

The Honolulu wholesale market for bottom fish was studied to assess the condition of the fishery and the status of the stocks. Six species comprise the preponderance of landings passing through this market (opakapaka, onaga, ehu, uku, hapuupuu, and butaguchi) and nearly all lots of bottom fish are of Hawaiian origin (89.6-96.9% between 1984 and 1986).

Total landings indicate the importance of opakapaka to the Hawaiian deep-sea handline fishery, although catches from the Northwestern Hawaiian Islands (NWHI) have declined 16.5% over the last 3 years. A trend of substitution by onaga is increasingly evident in the fishery. Catches of onaga, ehu, hapuupuu, and butaguchi from the NWHI have all increased substantially from 1984 to 1986. In contrast, bottom fish landings from the main Hawaiian Islands (MHI) have remained very stable (coefficient of variation = 3.0%).

Size structured yield-per-recruit analyses demonstrate that the MHI fisheries for opakapaka, ehu, and uku are moderately to severely growth-overfished. These species may benefit from minimum size restrictions. In contrast, an increased harvest of onaga in the MHI is suggested while the fishery for hapuupuu is close to optimal.

In the NWHI there is no evidence of growth-overfishing for any of the five species analyzed (opakapaka, onaga, ehu, hapuupuu, and butaguchi). This is likely due to the fishery being in a state of disequilibrium, the result of increasing fishing effort (30% increase in 3 years) and major changes in fishing grounds. In 1986 the fishery for bottom fish in the NWHI shifted almost 300 nmi to the northwest as more distant stocks were more heavily exploited.

Current harvest levels in the MHI are believed near maximum sustainable yield, although much better information concerning the recreational and unaccounted for commercial catch of these fishes is necessary before a more accurate assessment can be made. In the NWHI landings are presently in excess of the best available estimate of MSY as bottom fish stocks are "fished up." It is recommended that better data on the location of bottom fish harvests in the NWHI be obtained for future assessment work.

INTRODUCTION

As used by the fishermen of Hawaii and other island locations in the tropical Pacific, the term bottom fish refers to the complex of species typically caught with deep-sea handline gear. Most are snappers (lutjanids) and related forms (i.e., lethrinids and emmelichthyids), although groupers (epinepheline serranids), several species of jacks (carangids), and at least one scorpionfish (scorpaenid) are included in the fish community that is harvested by hook-and-line fishing gear in offshore waters 60-300 m deep. Bottom fish are usually found in habitats characterized by hard bottom of high structural complexity, restricting their accessibility to trawl and longline gears. Historically the Hawaiian deep-sea handline fishery for bottom fish has been one of the most important in the State, serving both commercial and recreational sectors of the community. A number of previous workers have studied and described aspects of the biology (Ralston and Polovina 1982; Ralston and Miyamoto 1983; Ralston 1984; Ralston, Gooding, and Ludwig 1986; Polovina 1987) and economics (Hau 1984; Pooley 1987) of this fishery (see also Hawaii Department of Land and Natural Resources 1979; Ralston 1979, 1982).

In 1986 a fishery management plan (FMP) was implemented by the Western Pacific Regional Fishery Management Council (Council) for the bottom fish and seamount groundfish fisheries of the western Pacific region (Hawaii, American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands). The plan was prepared under the guidelines of the Magnuson Fishery Conservation and Management Act of 1976 and is intended to result in the management of the bottom fish fishery so that optimal yields are realized.

The bottom fish FMP stipulates that every year a monitoring team appointed by the Council will assess the biological and economic conditions prevailing in the fishery and will prepare a report that presents its findings to the Council. If deemed necessary the team will suggest alternatives for corrective management action. The work presented here, by examining a variety of biological factors and fishery performance indicators that have been gleaned from a market sampling program, represents a biological contribution to the monitoring team's annual assessment of the fishery. Particular attention is paid to the size structure of certain key species in the Hawaiian fishery. This specific type of analysis has been used previously (Ralston and Kawamoto 1985) and is described in detail elsewhere (Ralston, Tagami, and Shiota 1986).

METHODS

The data used here were derived from a sampling program designed to monitor the landings of commercial fishermen at the centralized wholesale fish market in Honolulu. The fish passing through these market channels are a subset of the entire Statewide commercial bottom fish catch. Significant markets also exist on Maui, Hawaii, and Kauai. Moreover, there is without doubt a substantial recreational-subsistence harvest of bottom fish. The catch totals compiled here, therefore, do not represent meaningful absolute statistics. The value of monitoring the catch at this wholesale level is that it represents the most centralized point at which a large volume of landings can be intercepted and data economically collected. Because such a large share of the total Statewide catch of bottom fish is marketed there, trends and patterns in the data collected at the wholesale market are believed to be indicative of the fishery as a whole.

At the wholesale market bottom fish are auctioned either as individual fish or more commonly in lots. A lot is composed of a grouping of conspecific fish from a single fisherman's landings on a given day. Significantly, fish are sorted by size before assignment to lots, so that all those within a single lot tend to be of similar size (Ralston, Tagami, and Shiota 1986). For each lot of fish sold at the market it is possible to record the following information: (1) the species, (2) the total weight (lb) of the lot, (3) the number of individual fish comprising it, (4) the fishing vessel landing the catch, (5) the general location of fishing, (6) the purchaser, (7) the bid price, and (8) the date of the transaction. Previous work has shown that one can recover 88.0-99.3% of the information regarding actual bottom fish size structure by examination of these simple lot statistics (Ralston, Tagami, and Shiota 1986). Thus, size-frequency analysis of these data is possible.

The above data were recorded for all lots of bottom fish sold over the 3 years spanning 1984-86. The data were entered into a computer file in which each lot of fish comprises one record (observation) composed of the eight variables listed above. Various summary statistics were computed using Statistical Analysis System computer routines (SAS 1985a, 1985b, 1985c).

Weight-frequency distributions were compiled and analyzed in detail to estimate various biological and fishery dependent parameters. For each distribution considered the ascending portion of the curve (including the modal size class) was used to determine the weight at entry to the fishery (w_c) as suggested by Gulland (1969). Species were assumed fully vulnerable to the gear in all weight categories greater than, but not equal to, the mode. The descending portion of each weight-frequency distribution (excluding the mode) was transformed to a length-frequency polygon using the length-weight regressions provided in Loubens (1980), Uchiyama et al. (1983), Brouard and Grandperrin (1984), and Ralston (in press). In all cases analyzed the descending portions of catch length-frequency distributions were assumed to accurately depict stock size structure. This is equivalent to assuming constant selectivity of the gear (hooks) over the full size range of the descending limb, i.e., a "trawl" type sigmoidal selection curve. It is noteworthy that evidence exists in support of this assumption (Ralston 1982; Ralston unpublished data), although it is undoubtedly a simplification of what is in reality a complex interaction between the fish and the fishing gear.

The descending limbs of length-frequency distributions, pooled over 1984-86, were used to estimate the maximum length parameter (L_∞) of the von Bertalanffy growth model using the regression method of Wetherall et al. (in press). The data were pooled due to the instability of L_∞ estimates calculated for each year separately. The growth coefficient (K) of the von

Bertalanffy model was estimated from L_∞ using the growth performance equation derived specifically for snappers and groupers by Manooch (1987). This in turn was used to estimate the natural mortality rate (M) as suggested by Ralston (1987) in his study of snapper and grouper mortality rates. Total mortality rates (Z) were estimated from the descending limbs of length-frequency distributions using both the Beverton and Holt (1956) length-based estimator and the length converted catch curve method of Pauly (1982). In general there were no systematic differences between the two estimates of Z (Fig. 1), so they were averaged to produce a final estimate of Z. Instantaneous fishing mortality rates (F) were determined by subtraction (F = Z-M) and ages at entry to the fishery (t_c) were calculated from w_c, the length-weight regression, and the estimates of von Bertalanffy growth parameters. Maximum weight parameters (W_∞) were estimated with the values of L_∞ and the appropriate length-weight regression.

Yield-per-recruit analyses were conducted using the various parameters estimated from size structure (W_∞, K, M, F, and t_c). All species were assumed to recruit to the fishery at age I (i.e., constant natural mortality rate thereafter) and the simplified cubic form of the equilibrium Beverton and Holt (1957) yield equation based on isometric growth was used in lieu of the more complicated computations involving the incomplete beta function (Wilimovsky and Wicklund 1963). Previous calculations by Ralston (1981) using the latter had failed to appreciably alter the analytical result for opakapaka, Pristipomoides filamentosus. As suggested by Ricker (1975) the upper bound of the yield equation integral was assumed infinite.

In addition to total landings and size structure, another useful application of the wholesale market data set is the calculation of fishing effort and catch per unit effort (CPUE) statistics for the Northwestern Hawaiian Islands (NWHI) fishery. All bottom fishing trips to the NWHI tend to be of relatively short duration (approximately 2 weeks) because the product is marketed fresh at the wholesale market. For the same reason, when brought to port a vessel's landings are quickly sold. On the other hand the distance to the fishing grounds requires a minimum of 4 days transit time. Thus, it is possible to determine the number of fishing trips to the NWHI each year by following the pattern of sales at the market by individual fishermen. While on occasion it may require as much as 4 days to completely offload and sell the catch obtained from any particular trip to the NWHI, if 5 consecutive business days elapse at the wholesale market in which no subsequent transactions relating to that vessel occur, the sales from that trip can be considered complete. The total trip landings can then be determined by summation and, by examining the sales by all fishermen at the wholesale market, the total number of bottom fishing trips to the NWHI can be calculated for any given time period.

RESULTS

The data were first summarized to determine what species of bottom fish appear in the wholesale market samples. The results given in Table 1 show that many species are sold at the market, although a small subset accounts for the preponderance of lots. In particular, seven species (opakapaka,

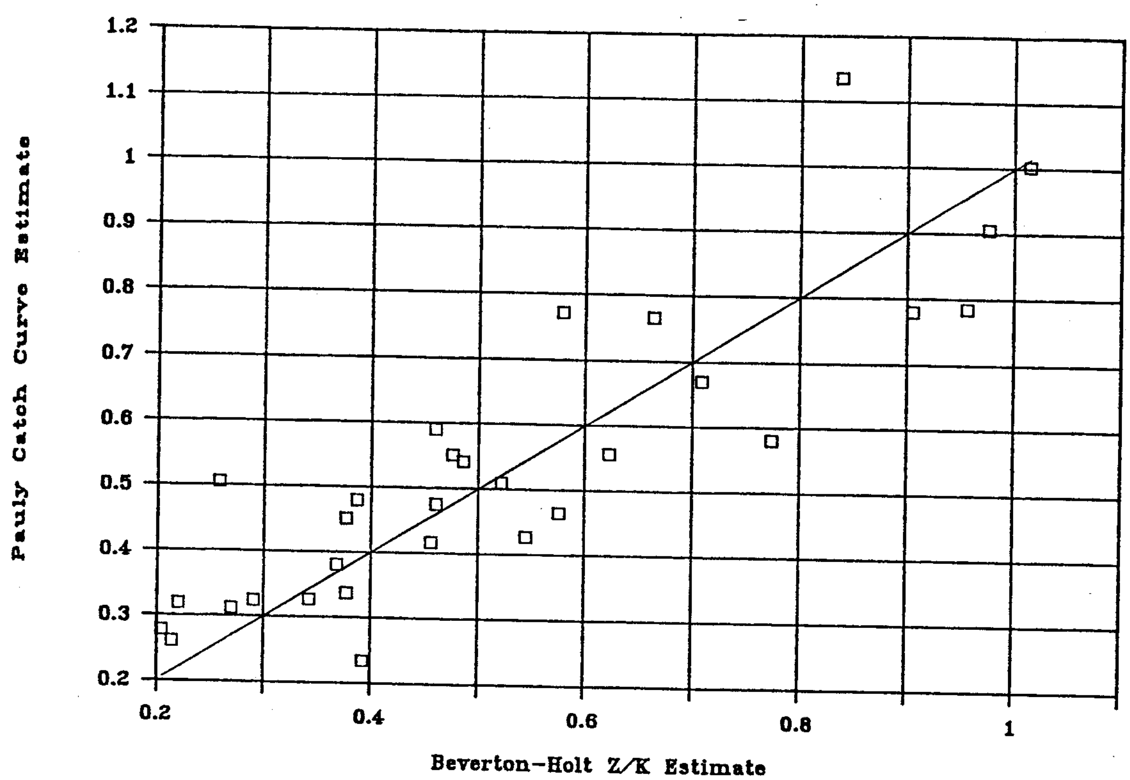


Figure 1.--A comparison of total mortality rate estimates (Z) derived from the Beverton and Holt (1956) length-based estimator and the Pauly (1982) length converted catch curve. The solid line represents equality of the estimates (units are per year).

Table 1.--Bottom fish species sold at the wholesale market from 1984 to 1986. The figures represent the percentage each species contributed to the total number of bottom fish lots in a year. A dash indicates trace quantities. Note that this table contains fish from areas other than Hawaii.

Family Species	Common name	1984	1985	1986
Lutjanidae				
Pristipomoides zonatus	Gindai	2.0	2.6	2.2
P. filamentosus	Opakapaka	28.8	20.0	18.8
P. sieboldii	Kalekale	3.8	5.3	3.9
P. flavipinnis	Yelloweye opakapaka	0.2	0.2	0.3
P. auricilla	Yellowtail kalekale	0.2	0.5	0.2
P. multidens	Goldbanded jobfish	0.1	0.4	0.4
P. argyrogrammicus	Ornate jobfish	--	--	--
P. typus	Sharptooth jobfish	--	--	--
Etelis coruscans	Onaga	14.7	21.4	21.2
E. carbunculus	Ehu	8.7	15.2	15.1
Lutjanus kasmira	Taape	2.8	3.5	2.4
L. fulvus	Toau	0.9	0.6	0.8
Aphareus rutilans	Lehi	1.9	2.9	1.6
A. furca	Hanui	0.3	0.2	--
Aprion virescens	Uku	9.1	2.6	4.6
Paracaesio spp.	Various	--	0.2	0.4
--	"Snapper"	--	0.2	--
Emmelichthyidae				
Erythrocles schlegelii	Golden kalekale	0.2	0.2	0.2
Serranidae				
Epinephelus quernus	Hapuupuu	9.0	8.2	8.6
Epinephelus spp.	Various	0.3	0.4	0.5
Carangidae				
Psuedocaranx dentex	Butaguchi, pig ulua	4.9	5.4	5.9
Caranx ignobilis	White ulua	3.7	3.8	2.6
Caranx and _Carangoides_ spp.	Ulua	7.2	4.5	8.1
Seriola spp.	Kahala	--	0.1	0.2
Scorpaenidae				
Pontinus macrocephalus	Hogo	1.1	1.5	1.6

onaga, ehu, uku, hapuupuu, butaguchi, and ulua) comprised 77.3-82.4% of all bottom fish lots sold from 1984 to 1986. The total numbers of bottom fish lots recorded during these years were 22,461, 34,612, and 39,840, respectively.

Fishing areas for the bottom fish sold at the wholesale market from 1984 to 1986 are presented in Table 2. In this table all areas are mutually exclusive categories, i.e., if a lot appears under the Twin Banks heading it does not appear under either the NWHI or Hawaiian Islands headings. Examination of the data in the table shows that out of State sales of fish are assuming increasing importance. Whereas in the past only American Samoa and Fiji shipped bottom fish to the wholesale market on a regular basis, in 1986 a wide variety of Pacific island nations marketed bottom fish in Honolulu. Nonetheless, bottom fish caught in Hawaii represent the vast majority of the market sampling data. In the first year of sampling 96.9% of all bottom fish lots were composed of fish caught in Hawaii. For the subsequent 2 years the figures are 93.9 and 89.6%.

A significant development in the collection of the location data is that the precision of the information has steadily improved. Since 1984, both the fraction and number of bottom fish lots classified to the "Hawaiian Islands" area category declined to zero. In 1986 it was possible to assign all Hawaiian bottom fish landings to either the main Hawaiian Islands (MHI) or the NWHI categories. Likewise, within the NWHI region, only 15% of the lots sampled in 1984 had the specific bank of harvest recorded. In 1986 the situation was reversed; 64% of all NWHI bottom fish lots were classified to specific bank or island locations. In spite of the marked improvement in the collection of the 1986 data, the fairly crude geographical resolution that characterizes the first 2 years of data precludes detailed treatment on a bank by bank basis. For this reason, the fundamental separation of MHI and NWHI landings was the only areal distinction made in the yield analyses that follow.

Moreover, due to the abundance of lot statistics for opakapaka, onaga, ehu, uku, hapuupuu, and butaguchi, and the relative paucity of data concerning the remaining species, detailed analyses were conducted only on this subset of species. Note that although "ulua" accounts for a substantial number of lots (4.5-8.1%), it is a heterogeneous group of species, each of uncertain taxonomic affiliation.

Landings of Hawaiian Bottom Fish at the Wholesale Market

The data presented in Table 3 summarize the total Hawaiian landings of opakapaka, onaga, ehu, uku, hapuupuu, butaguchi, and total bottom fish. The figures given represent only the catch that is known to have been caught in either the MHI or the NWHI. However, the remaining "Hawaiian Islands" catch (see Table 2) amounts to no more than 3.4% of these totals. In aggregate this catch represents 82.4-86.9% of all the bottom fish sold at the wholesale market from 1984 to 1986, regardless of species or area caught.

Table 2.--Harvest locations of bottom fish appearing at the wholesale market during 1984-86. The figures represent the percentage each area contributed to the total number of bottom fish lots in a year. A dash indicates trace quantities and a zero no recorded landings. All area categories are treated as mutually exclusive.

Area	1984	1985	1986
Hawaiian Islands	2.4	1.3	0
Main Hawaiian Islands	3.7	2.2	0.4
Hawaii	10.0	18.0	12.3
Maui	0.5	--	0.2
Molokai	1.6	2.7	3.1
Oahu	37.0	31.1	37.0
Kauai	7.1	6.1	2.3
Northwestern Hawaiian Islands	29.5	29.7	12.3
Middle Bank	0.1	0	0.6
Nihoa	--	0.1	0.8
Twin Banks	0	0.9	0.3
Necker Island	0.6	0.3	1.3
French Frigate Shoals	1.0	0.3	0.9
Brooks Banks	2.6	0	0.5
Gardner Pinnacles	0.4	0	2.4
Raita Bank	0	0	1.5
Maro Reef	0	0	0.7
Laysan Island	0.4	0.1	1.4
Northampton Seamounts	0	0	0.8
Pioneer Bank	0	0.2	1.0
Lisianski Island	0	0	9.0
Pearl and Hermes Reef	0	0	0.6
Line Islands	0	0	0.1
Tahiti	0	--	0
American Samoa	2.1	0.6	1.2
Western Samoa	0	0	--
Tonga	0	--	0.1
Fiji	0.9	3.3	6.8
Vanuatu	0	--	0.1
Federated States of Micronesia	0	0	0.1
Pohnpei	0	0	--
Yap	0	0	--
New Zealand	0	0	0.2
Australia	0	0	1.5
Palau	0	2.1	0.1
Guam	0	0.1	0.1
Taiwan	0	0	0.1

Table 3.--Total landings (in metric tons) of Hawaiian bottom fish from the main Hawaiian Islands and the Northwestern Hawaiian Islands.

	1984	1985	1986
Opakapaka			
Main Hawaiian Islands	37.5	30.9	34.2
Northwestern Hawaiian Islands	143.4	140.5	119.8
Onaga			
Main Hawaiian Islands	36.7	64.4	56.2
Northwestern Hawaiian Islands	3.1	23.4	43.1
Ehu			
Main Hawaiian Islands	6.5	12.9	11.6
Northwestern Hawaiian Islands	2.2	9.3	11.8
Uku			
Main Hawaiian Islands	31.1	8.1	20.1
Northwestern Hawaiian Islands	3.4	0.7	3.0
Hapuupuu			
Main Hawaiian Islands	6.7	3.4	3.4
Northwestern Hawaiian Islands	46.1	66.5	84.3
Butaguchi			
Main Hawaiian Islands	0.8	0.4	0.6
Northwestern Hawaiian Islands	29.5	56.2	63.5
All six species			
Main Hawaiian Islands	119.4	120.1	126.0
Northwestern Hawaiian Islands	227.7	296.5	325.5

It is apparent from these results that opakapaka has been the mainstay of the bottom fish fishery in Hawaii, especially if only the NWHI is considered. For example, this species alone comprised over half the Hawaiian bottom fish share of the wholesale market in 1984. However, there has been a marked (16.5%) decline in the harvest of this species in the NWHI over the period in question. In contrast, landings from the MHI appear to be relatively stable.

Onaga is the second most important species in the Hawaiian deep-sea handline fishery, contributing 22.0% to the 1986 total. In contrast to opakapaka, the catch of this species has generally risen from 1984 to 1986, most notably in the NWHI where landings increased fourteenfold in 3 years. Moreover, in the last 3 years the onaga catch from the MHI has generally exceeded opakapaka landings from the same area.

From 1984 to 1986 the catch of ehu from the NWHI increased markedly, likely in direct association with the increase in onaga landings. Both species inhabit deeper habitats than opakapaka and, for that reason, they tend to co-occur in the catch (Ralston and Polovina 1982).

As measured by the coefficient of variation (CV), landings of uku from the MHI are highly variable (CV = 58%). The fishery for this species is very seasonal during the early summer months (Ralston 1979), a time when uku aggregate to spawn. Because no other Hawaiian bottom fish is known to similarly aggregate, this aspect of the life history may be related in some way to the relatively high variation in catch between years. Moreover, it is evident from the data in Table 3 that compared with the MHI, the NWHI harvest of uku is presently negligible. Insufficient numbers of uku were recorded from the NWHI region to perform a size structured analysis of yield per recruit, although a number of fishermen have displayed an increasing interest in the Middle Bank and Necker Island stocks of uku.

Like the onaga and ehu, landings of hapuupuu from the NWHI have increased dramatically in recent years (83%). While substantially less than the NWHI, the MHI catch is nonetheless of sufficient magnitude to allow a yield analysis. The data suggest that the MHI hapuupuu catch may be waning. Overall the hapuupuu is the third most important species of bottom fish in the Hawaiian fishery on the basis of landed weight, trailing opakapaka and onaga.

The geographical distribution of butaguchi is limited almost entirely to the NWHI, where almost 99% of all landings are taken. This pattern is reciprocal to that of the uku. Consequently, insufficient quantities of butaguchi were landed from the MHI to analyze further. In parallel with onaga, hapuupuu, and ehu, landings of butaguchi from the NWHI show a steady increase from 1984 to 1986, rising 115% during this time.

The general pattern of the wholesale market landings of these six species taken together shows a distinct difference between the trends in the MHI and NWHI regions. In aggregate, over the 3-year span for which there are data, the MHI catch has been very stable (CV = 3.0%) while the NWHI catch has increased 43.0%.

It is also of considerable interest to compare the wholesale market landings of bottom fish from the MHI and the NWHI with our current estimates of the maximum sustainable yield (MSY) from these areas. In a memorandum to the members of the Bottom Fish Planning Team dated 27 March 1986, Stephen Ralston of the National Marine Fisheries Service, Southwest Fisheries Center Honolulu Laboratory summarized information pertaining to estimates of bottom fish productivity (Ralston and Polovina 1982; Polovina 1984; Polovina and Ralston 1986) and habitat area within the Hawaiian Islands. Bottom fish MSY for the MHI was estimated to be 285 t, while for the primary fresh access zone of the NWHI (Nihoa to Lisianski Island) it was set at 275 t. The data presented in Table 3 show that over the last 3 years the MHI "wholesale market" harvest level has been stable at a value somewhat less than our best estimate of MSY. In fact, these data indicate that only 43% of the potential MHI yield is being caught and marketed at the wholesale level. By comparison the 1986 NWHI catch of bottom fish sold at the wholesale market is substantially in excess of the projected MSY (18% greater).

Size Structured Analysis

In this section the size structure of six different species (opakapaka, onaga, ehu, uku, hapuupuu, and butaguchi) will be considered in some detail. Moreover, the wholesale market landings of these fishes have been separated into MHI and NWHI categories. As previously indicated, the NWHI catch of uku and the MHI catch of butaguchi were insufficient to perform yield-per-recruit analyses. This leaves 10 different species by area combinations to examine.

Main Hawaiian Islands Opakapaka

Weight-frequency histograms for the 1984-86 catch of MHI opakapaka are presented in panels A-C of Figure 2. Note that the presence of individuals in the "0" pound weight class (e.g., for 1984 and 1986) indicates the existence of some illegal fish weighing 0.00-0.50 lb. This is because all weights were rounded to the nearest integer. Note also that the modal size of MHI opakapaka dropped from 1.36 kg (3 lb) in 1984 to 0.91 kg (2 lb) in 1985 and 1986.

Panel D of Figure 2 provides the relative length structure of MHI opakapaka during the time period in question. These data, jointly and in isolation, were used to estimate the following parameters: L_∞, W_∞, Z, w_c, and t_c (Table 4). It was then possible to perform a yield-per-recruit analysis (Fig. 3), the results of which indicate that over the 1984-86 period the age at entry to the fishery (t_c) has dropped substantially as fishing mortality rate has increased. If the current trend continues yield per recruit will decline. Ralston and Kawamoto (1985) believed the 1984 value of t_c to be slightly less than 2.0 years, while that given here is approximately 3.0. The difference in estimates is due to the more limited data available to the former study (1,347 MHI opakapaka sampled in the 6 weeks from mid-January to the end of February). In any event, the primary conclusion at this point is that the age at entry is presently too low.

Northwestern Hawaiian Islands Opakapaka

Similar data are presented in Table 4 and Figures 4 and 5 for the NWHI "stock" of opakapaka. The histograms show that NWHI opakapaka are generally much larger than their MHI counterparts. Relatively speaking, very few small fish are landed from the NWHI, i.e., t_c is quite high. Neither is there evidence of growth overfishing due to excessive fishing effort. Moreover, the current trend appears to indicate a lessening of fishing mortality and an increase in the age at entry. This result is likely due to relatively unexploited fishing grounds being targeted in 1985 and 1986, with the catch demonstrating a virgin size structure (see section on

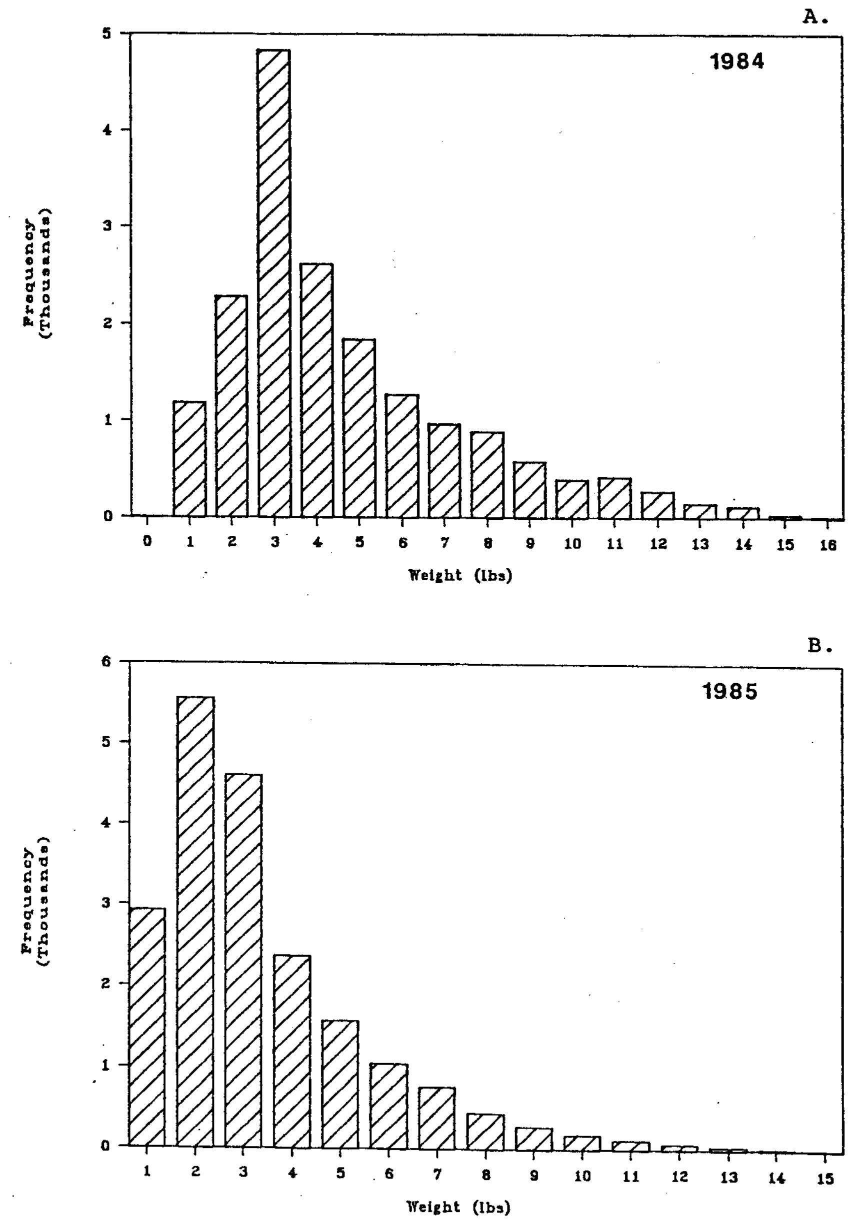
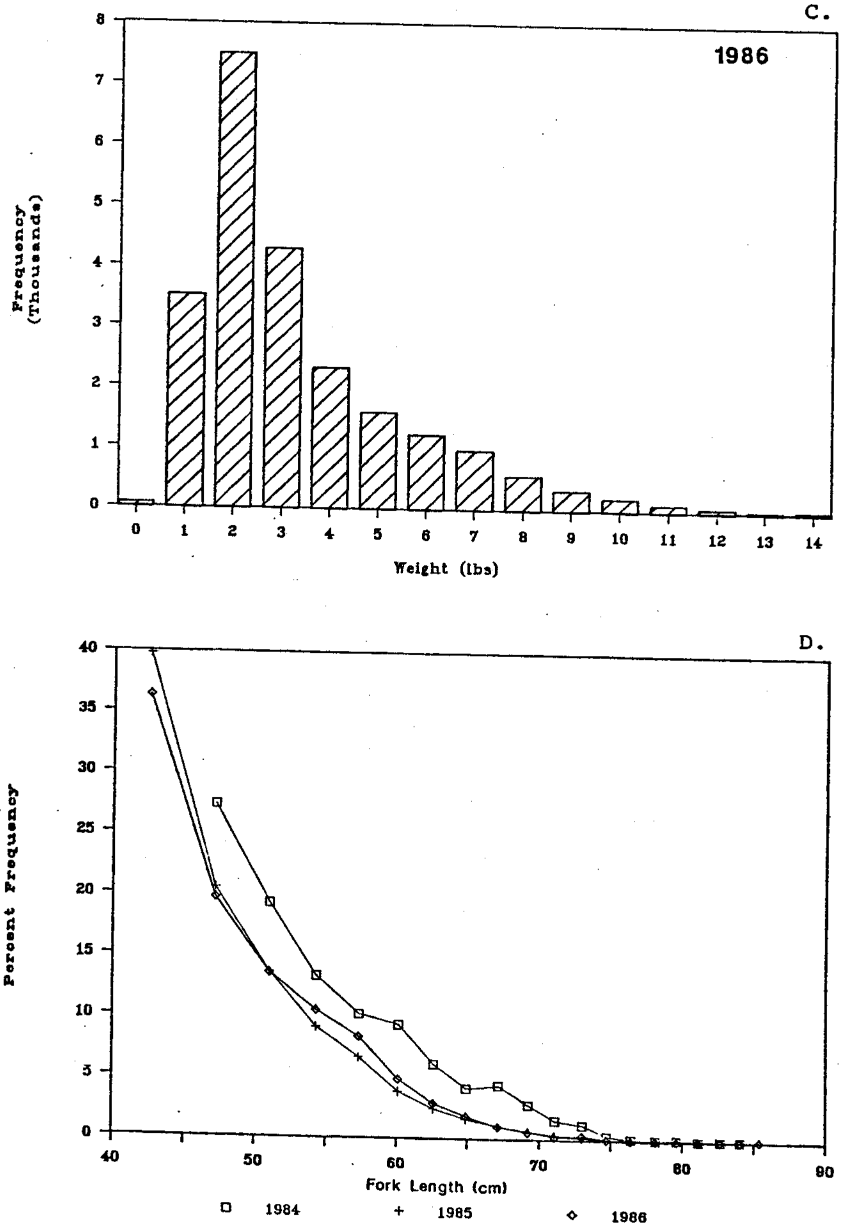


Figure 2.--Size structure of opakapaka landed from the main Hawaiian Islands over the period 1984-86. The first three panels (A-C) provide the weight-frequency histograms for each year. The fourth panel (D) is an overlay of the annual relative length-frequency polygons.



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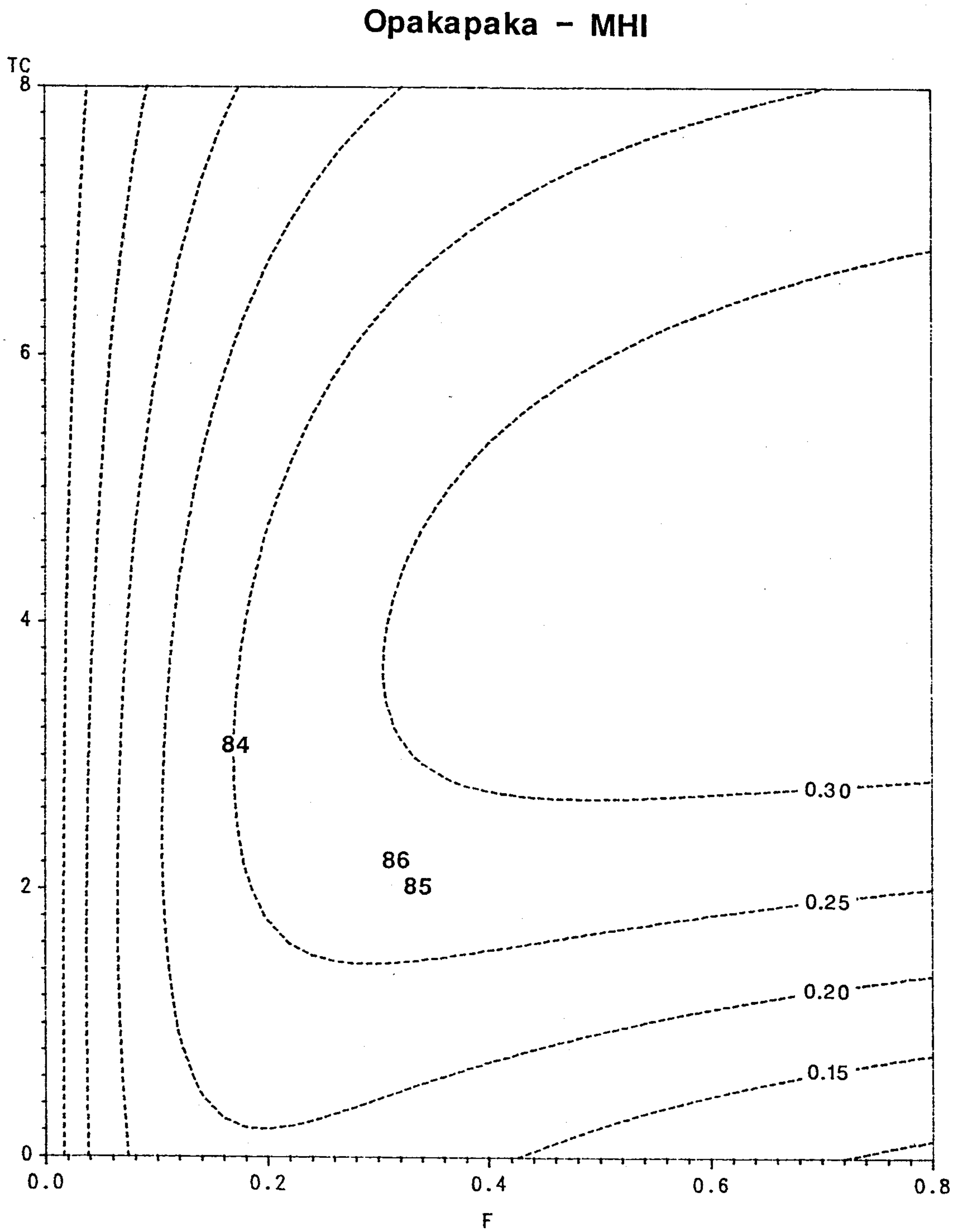
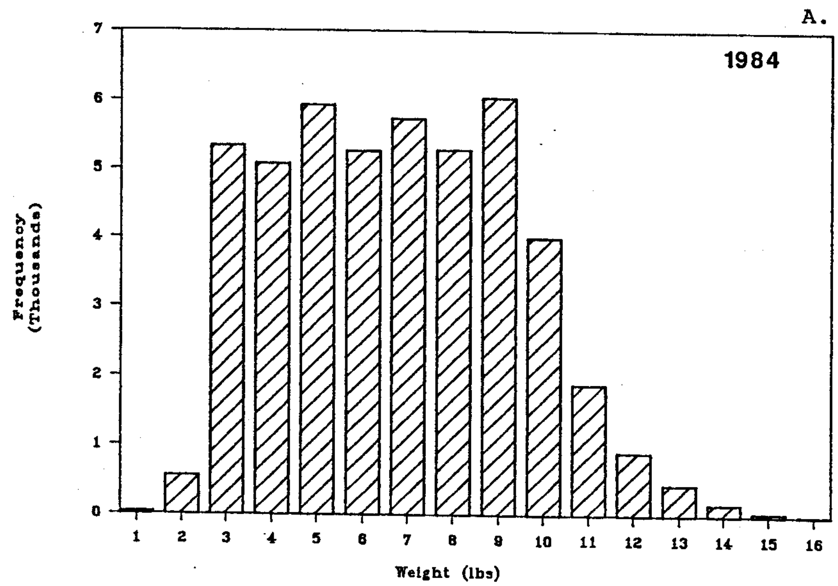


Figure 3.--Yield-per-recruit analysis for opakapaka caught in the main Hawaiian Islands. The unit of F is per year and the unit of t_c is years. Contoured isopleths represent the locus of points corresponding to equal yield per recruit (kg). The estimated positions of the fishery during the years 1984, 1985, and 1986 are plotted.



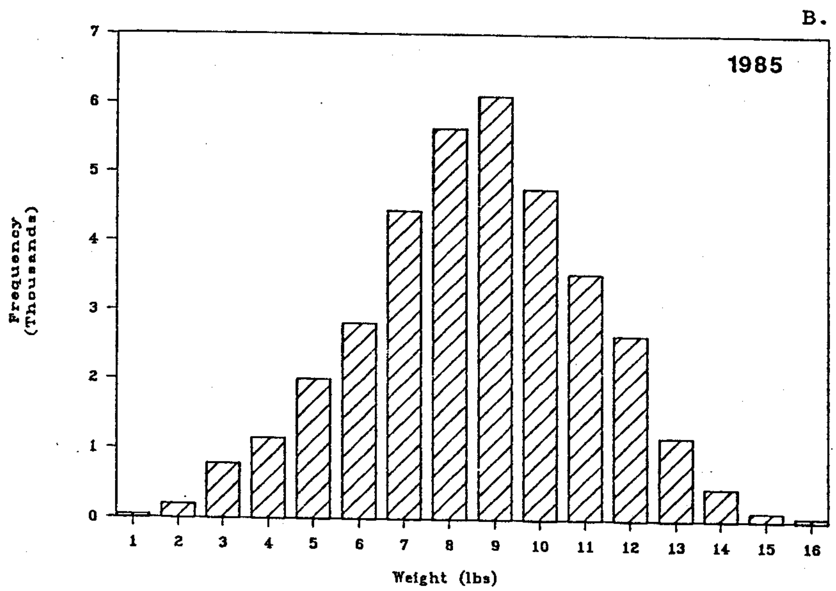
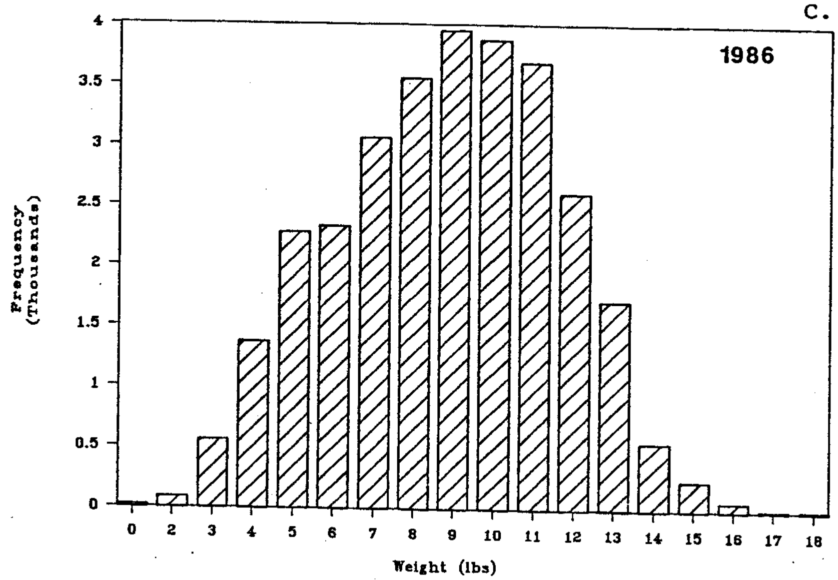


Figure 4.--Size structure of opakapaka landed from the Northwestern Hawaiian Islands over the period 1984-86. The first three panels (A-C) provide the weight-frequency histograms for each year. The fourth panel (D) is an overlay of the annual relative length-frequency polygons.



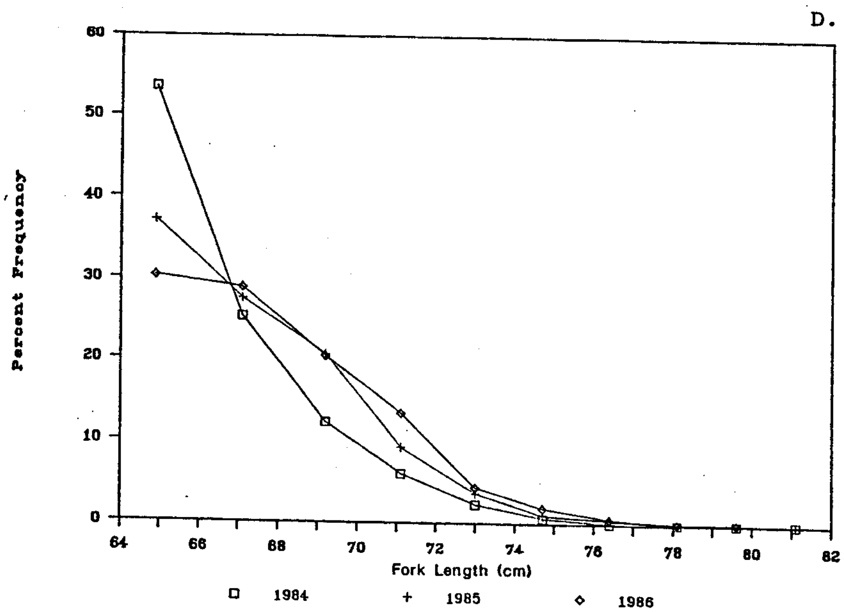


Figure 4.--Continued.

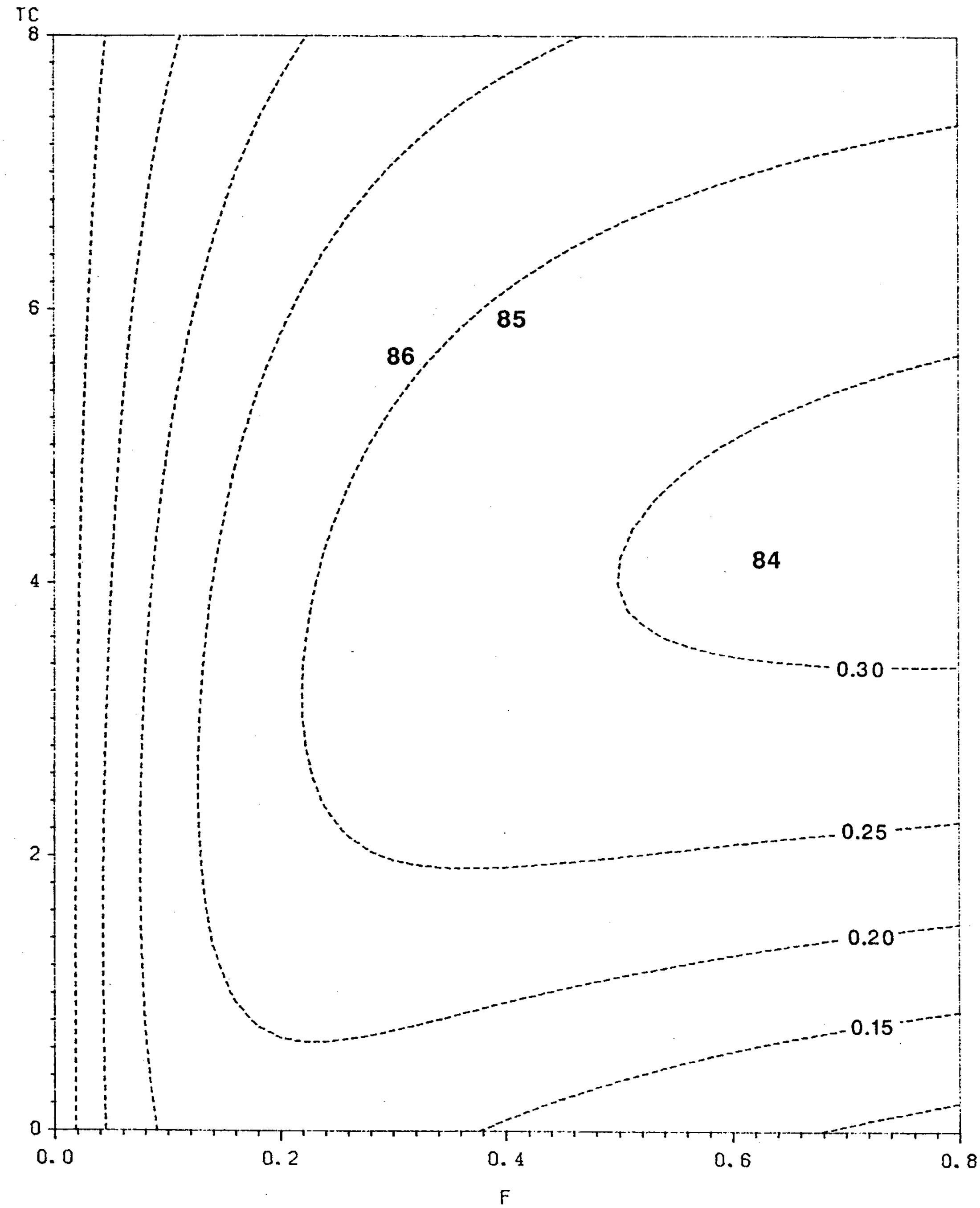


Figure 5.--Yield-per-recruit analysis for opakapaka caught in the Northwestern Hawaiian Islands. The unit of F is per year and the unit of t_c is years. Contoured isopleths represent the locus of points corresponding to equal yield per recruit (kg). The estimated positions of the fishery during the years 1984, 1985, and 1986 are plotted.

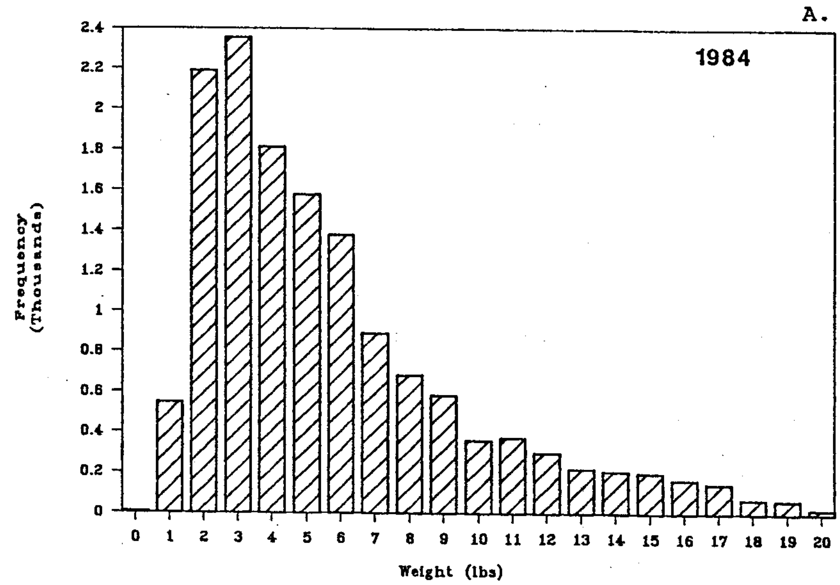
Table 4.--Parameter estimates for bottom fish yield assessments: L_∞ = von Bertalanffy asymptotic length (cm), $SE(L_\infty)$ = standard error of L_∞, K = von Bertalanffy growth coefficient (per year), M = natural mortality rate (per year), W_∞ = von Bertalanffy asymptotic weight (kg), w_c = weight at entry to the fishery (kg), t_c = age at entry to the fishery (year), F = fishing mortality rate (per year).

	Opakapaka		Onaga		Ehu		Uku	Hapuupuu		Butaguchi
	MHI	NWHI	MHI	NWHI	MHI	NWHI	MHI	MHI	NWHI	NWHI
L_∞	86.6	83.7	89.4	95.7	82.1	69.4	116.5	118.6	108.0	98.6
$SE(L_\infty)$	1.62	3.12	0.63	1.59	2.21	1.06	3.64	0.70	1.02	1.62
K	0.146	0.150	0.143	0.137	0.151	0.169	0.120	0.119	0.126	--
M	0.293	0.299	0.287	0.274	0.303	0.338	0.241	0.238	0.253	--
W_∞	10.4	9.43	10.8	13.2	10.3	6.13	24.35	32.13	24.03	17.2
1984										
w_c	0.8	1.4	0.6	4.3	0.2	0.6	2.3	1.4	1.0	2.8
t_c	2.97	4.18	2.56	7.64	1.49	3.09	4.61	3.15	2.87	--
F	0.16	0.61	0.05	0.14	0.55	0.15	0.51	0.12	0.00	--
1985										
w_c	0.4	2.6	0.6	3.7	0.2	0.6	2.0	1.3	1.1	3.6
t_c	2.02	6.14	2.56	6.89	1.49	3.09	4.29	3.04	3.01	--
F	0.33	0.37	0.01	0.26	0.75	0.06	0.44	0.11	0.00	--
1986										
w_c	0.5	2.3	0.5	3.8	0.2	0.7	2.4	1.3	1.1	2.1
t_c	2.28	5.67	2.32	7.02	1.49	3.36	4.70	3.04	3.01	--
F	0.28	0.28	0.00	0.20	0.70	0.13	0.70	0.12	0.00	--

geographical patterns of fishing in the NWHI). Additionally there is a trend within the NWHI fishery to use larger size hooks, perhaps favoring the catch of larger fish (but see Ralston 1982).

Main Hawaiian Islands Onaga

The data presented in Table 4 and Figures 6 and 7 form the basis for a assessing the MHI fishery for onaga. The histograms indicate that, like the opakapaka, onaga are entering the fishery at a very small size (a 2-lb mode in 1985 and 1986). However, the length-frequency polygon overlay for the data from all 3 years (panel D, Fig. 6) provides no indication of a high mortality rate. The descending limbs of all three curves do not show excessive curvature. These results are indicative of a stock under light exploitation, as evidenced by the low estimates of fishing mortality in Figure 7. Even with the low age at entry to the fishery there is at present no indication that the resource is overfished. To the contrary, all the evidence suggests that MHI onaga are presently underutilized.



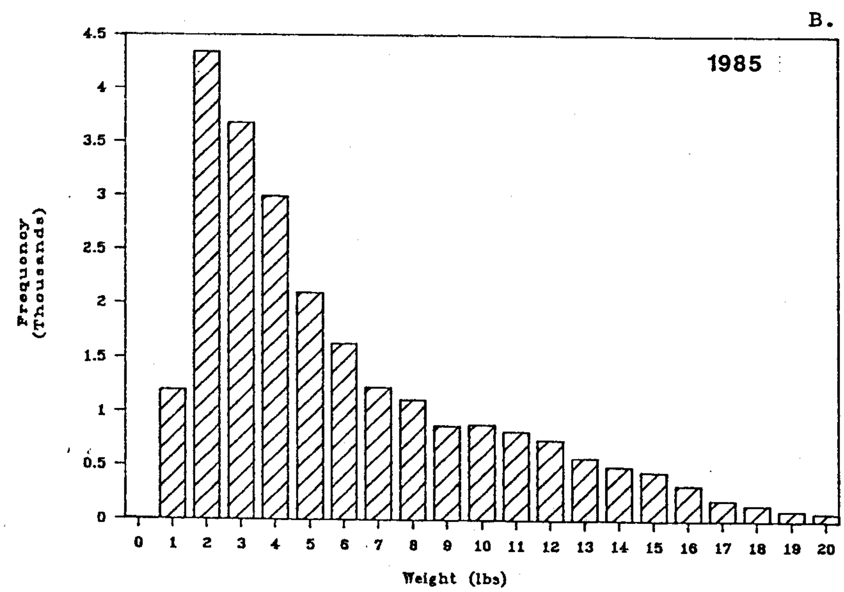
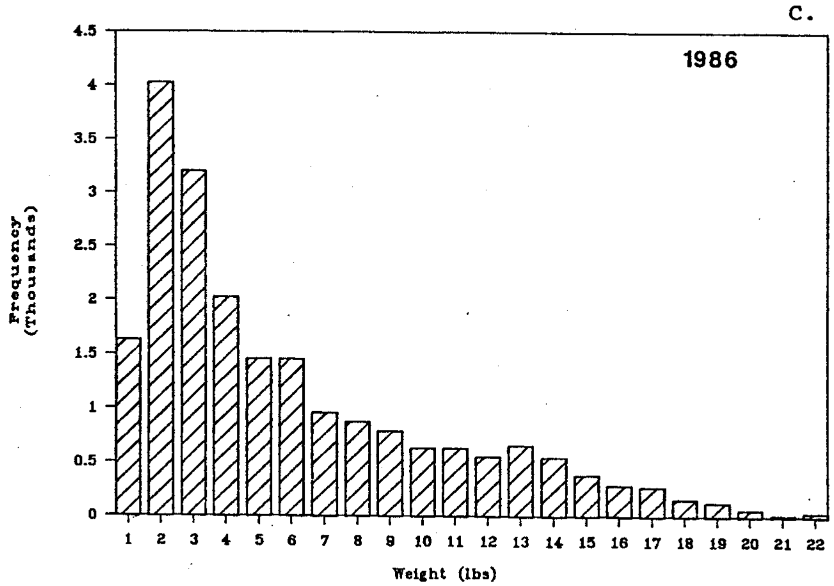


Figure 6.--Size structure of onaga landed from the main Hawaiian Islands over the period 1984-86. The first three panels (A-C) provide the weight-frequency histograms for each year. The fourth panel (D) is an overlay of the annual relative length-frequency polygons.



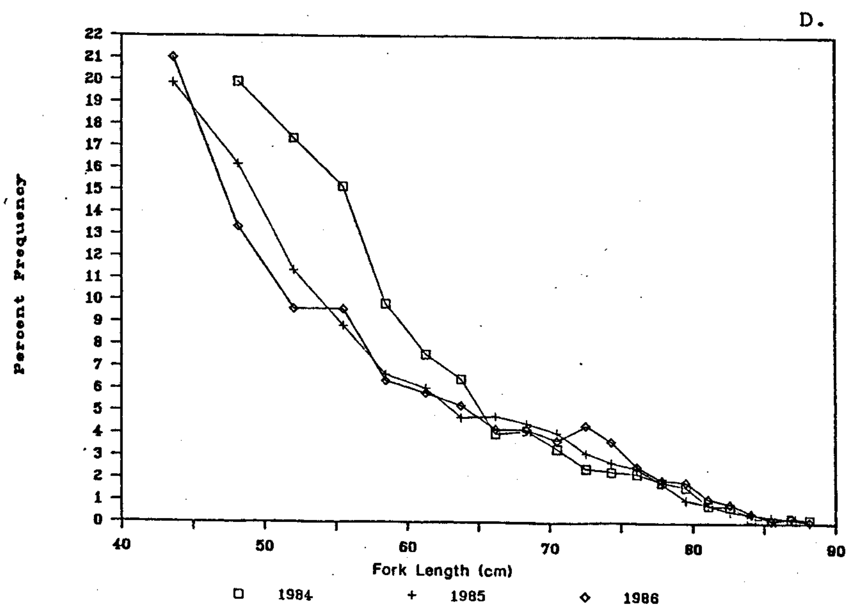


Figure 6.--Continued.

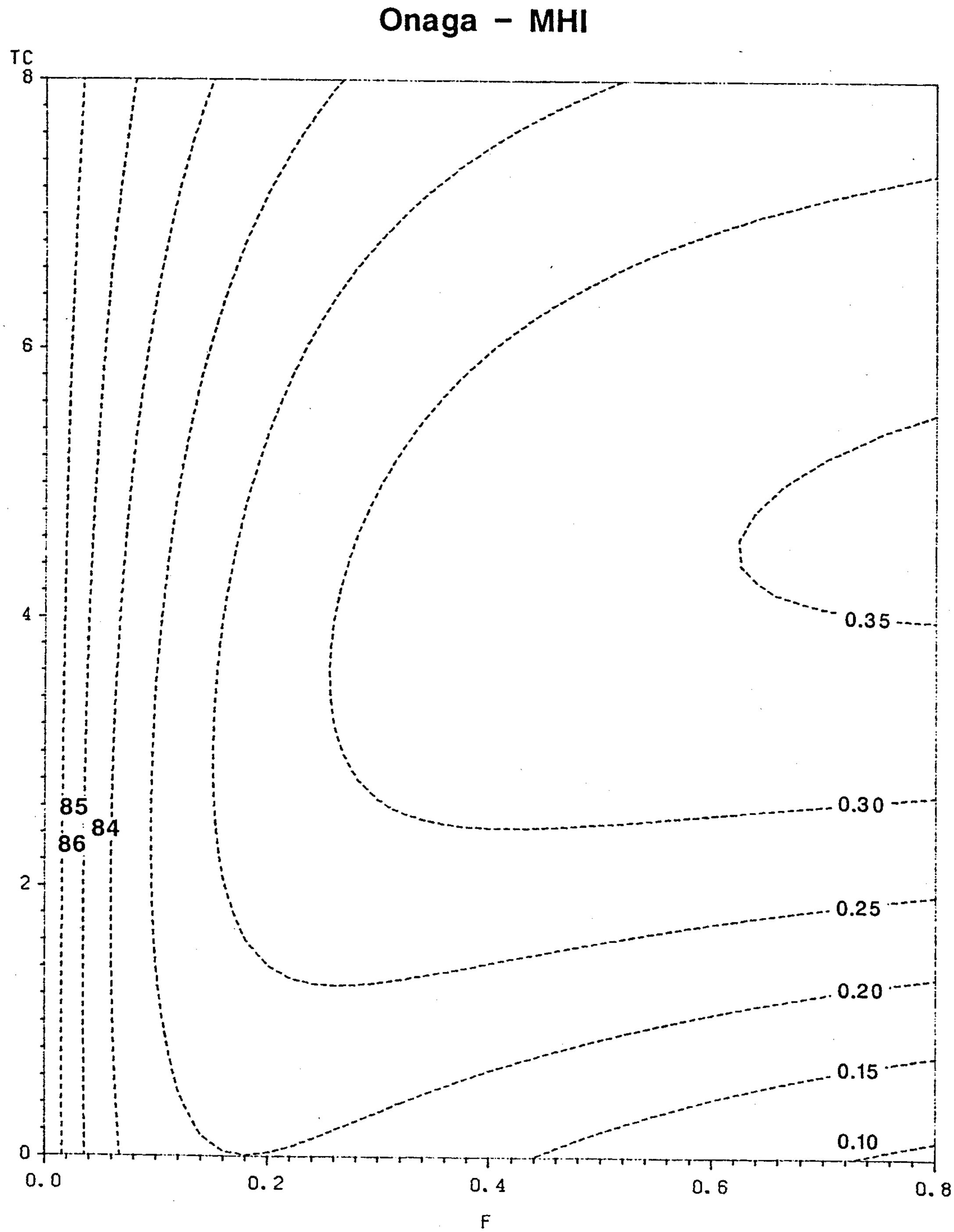


Figure 7.--Yield-per-recruit analysis for onaga caught in the main Hawaiian Islands. The unit of F is per year and the unit of t_c is years. Contoured isopleths represent the locus of points corresponding to equal yield per recruit (kg). The estimated positions of the fishery during the years 1984, 1985, and 1986 are plotted.

Northwestern Hawaiian Islands Onaga

The analysis for NWHI onaga indicates a very high age at entry to the fishery (greater than 6 years) and a moderate level of fishing mortality (Table 4; Figs. 8 and 9). Because the modes of the histograms for 1984-86 are all in excess of 11 lb, the descending limbs presented in the relative length-frequency polygon overlay (panel D, Fig. 8) span a very small range in length, approximately 15 cm. This narrow range exacerbates the problem of estimating mortality rates due to the increased likelihood of substantial measurement and sampling errors. The fishery for onaga in the NWHI is relatively new, as evidenced by the fact that only 3.1 t were landed in 1984 (see discussion above). A change in size structure that would lead to a significant estimate of fishing mortality is not to be expected over so short a time interval. As pointed out by Ricker (1975), "survival rates which we estimate from age frequencies in a catch are ancient history." The same holds true for length frequencies. The estimates of fishing mortality for onaga caught in the NWHI (Table 4 and Fig. 9) are therefore in need of further validation and study.

Main Hawaiian Islands Ehu

Presented in Table 4 and Figures 10 and 11 are the results concerning the MHI fishery for ehu. It is clear that this species does not reach the large size characteristic of opakapaka and onaga. It is also apparent that, like the MHI fisheries for these other species, the age at entry for the ehu fishery is very low. The mode of all three histograms for the years 1984-86 is 1 lb. But unlike MHI onaga, substantial curvature exists in the descending limbs of the length-frequency polygons (panel D, Fig. 10). This characteristic is indicative of a high fishing mortality, at least for snappers and groupers (Ralston 1987). The yield-per-recruit analysis suggests that the fishery is overexploited (Fig. 11). Based on the data available, an increase in the age at entry to the fishery (t_c) would have a substantially beneficial effect on yield.

Northwestern Hawaiian Islands Ehu

A similar analysis was performed on the NWHI stock of ehu, the results of which are presented in Table 4 and Figures 12 and 13. When compared with the MHI, the ehu that are harvested in the NWHI are of a much larger size. Fish are entering the fishery at a weight three times that of the MHI (compare values of w_c in Table 4). Likewise, the age at entry is over twice as great. Neither is there excessive curvature in the descending limbs of the length-frequency distributions for 1984-86. The overall result (Fig. 13) is that the NWHI fishery for ehu is not fully utilized. Improvements to yield could be realized by increasing the existing level of fishing mortality.

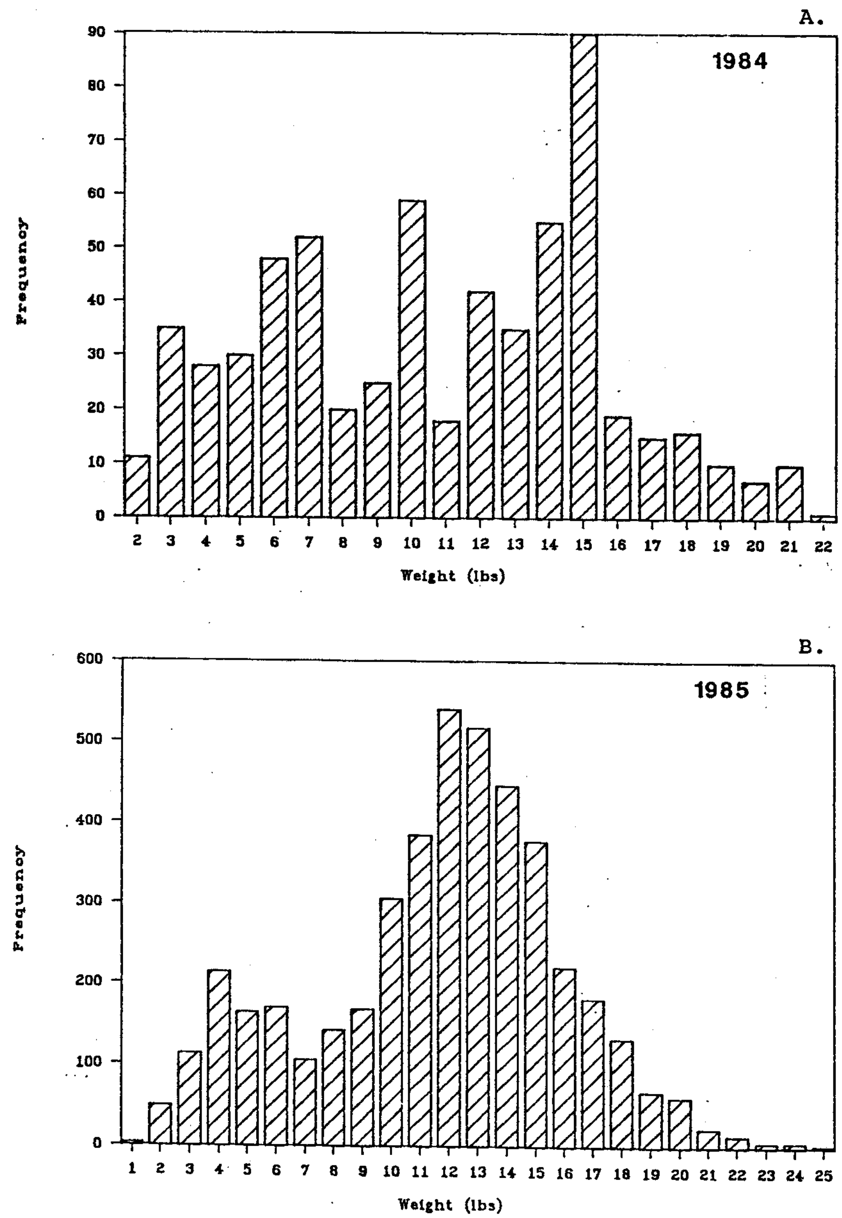
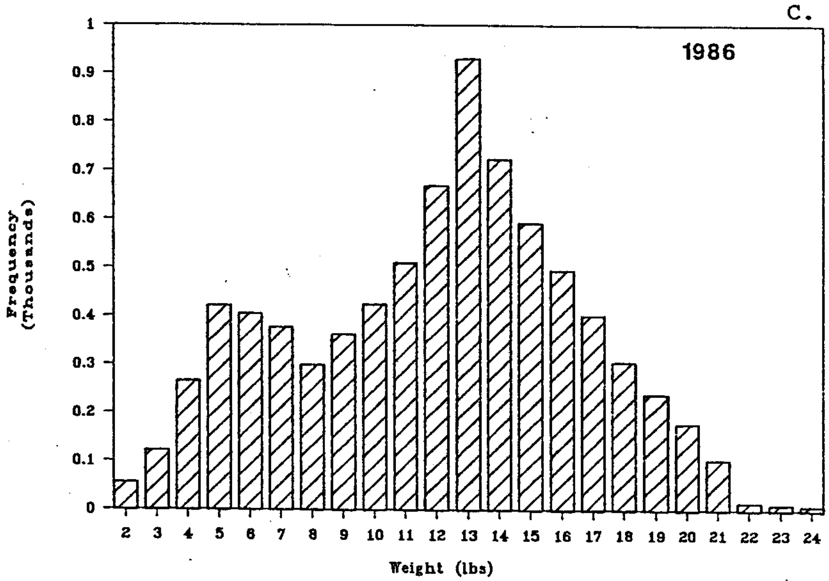


Figure 8.--Size structure of onaga landed from the Northwestern Hawaiian Islands over the period 1984-86. The first three panels (A-C) provide the weight-frequency histograms for each year. The fourth panel (D) is an overlay of the annual relative length-frequency polygons.



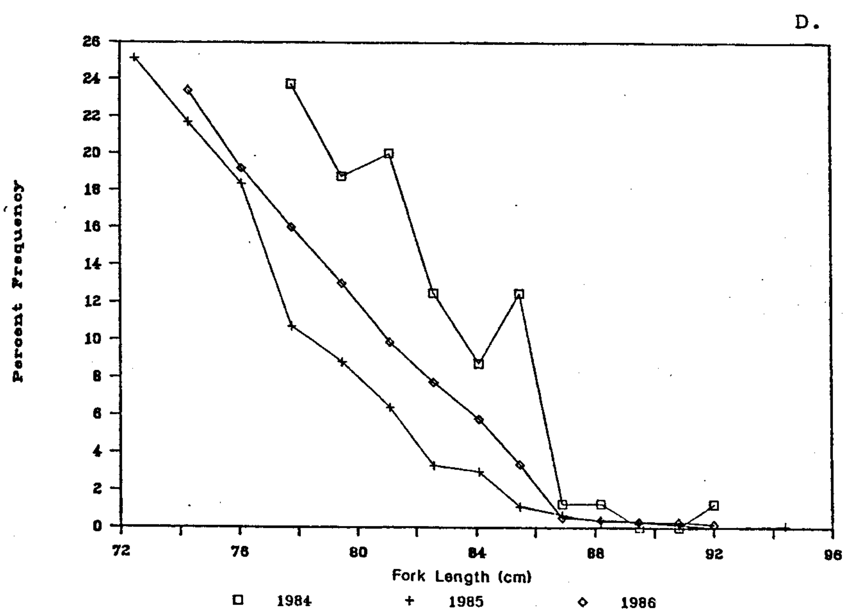


Figure 8.--Continued.

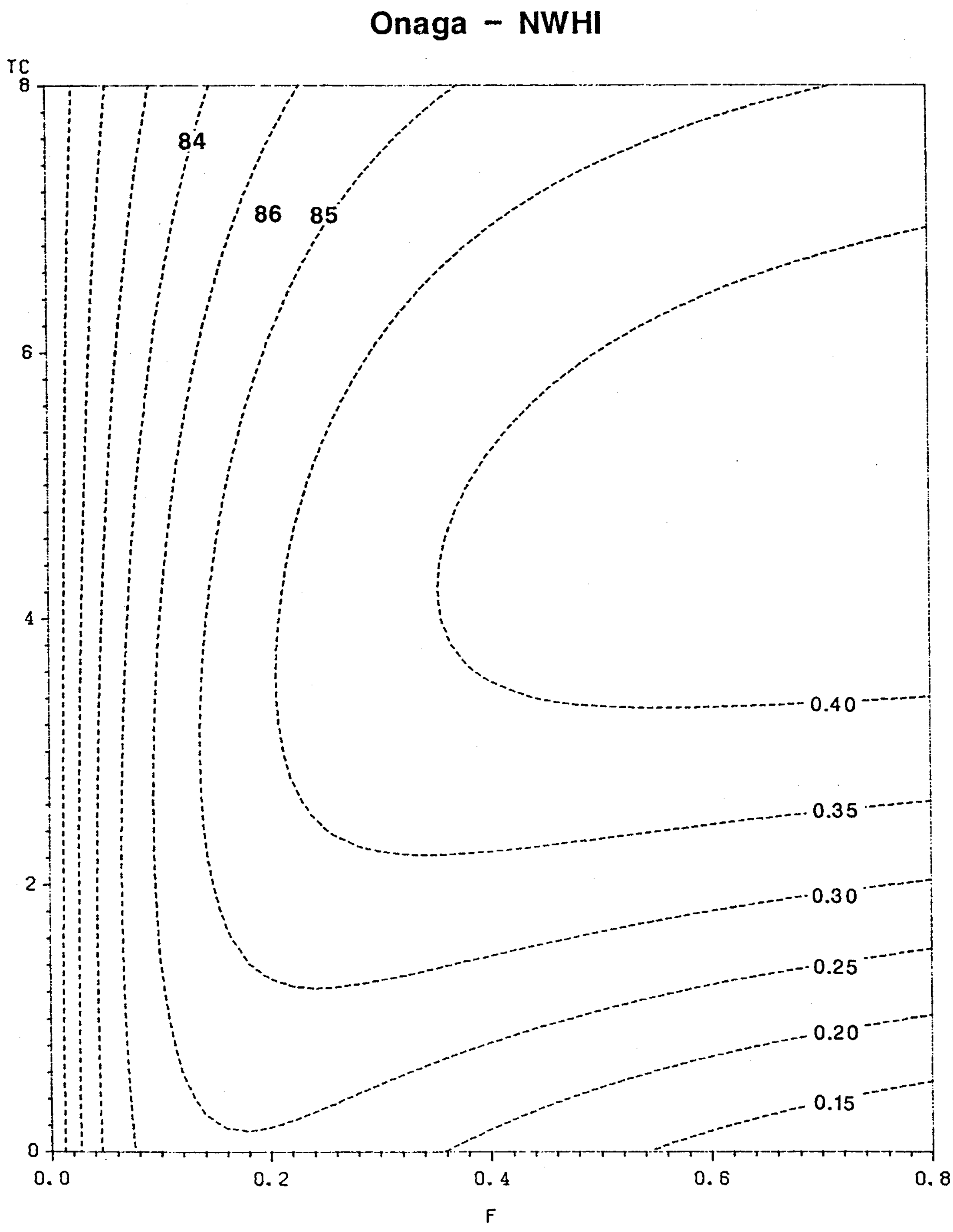


Figure 9.--Yield-per-recruit analysis for onaga caught in the Northwestern Hawaiian Islands. The unit of F is per year and the unit of t_c is years. Contoured isopleths represent the locus of points corresponding to equal yield per recruit (kg). The estimated positions of the fishery during the years 1984, 1985, and 1986 are plotted.

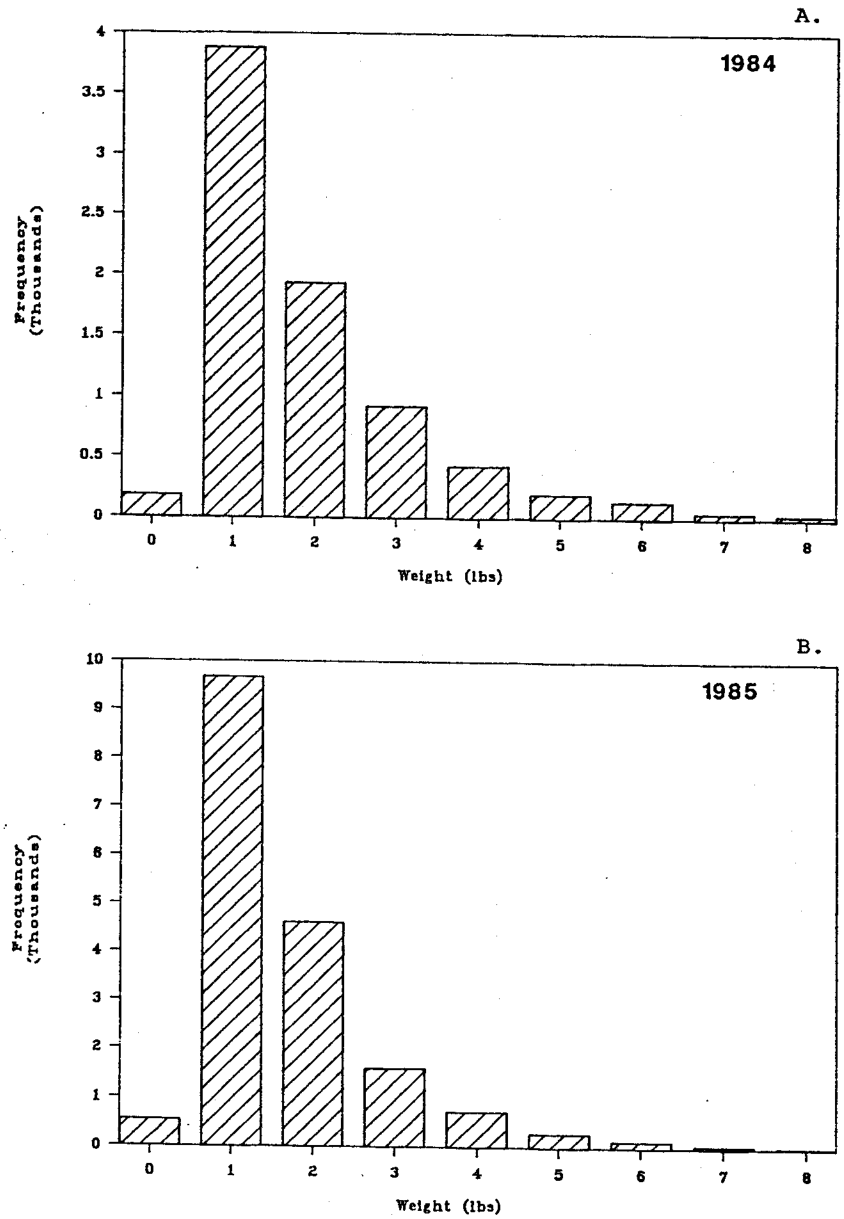


Figure 10.--Size structure of ehu landed from the main Hawaiian Islands over the period 1984-86. The first three panels (A-C) provide the weight-frequency histograms for each year. The fourth panel (D) is an overlay of the annual relative length-frequency polygons.

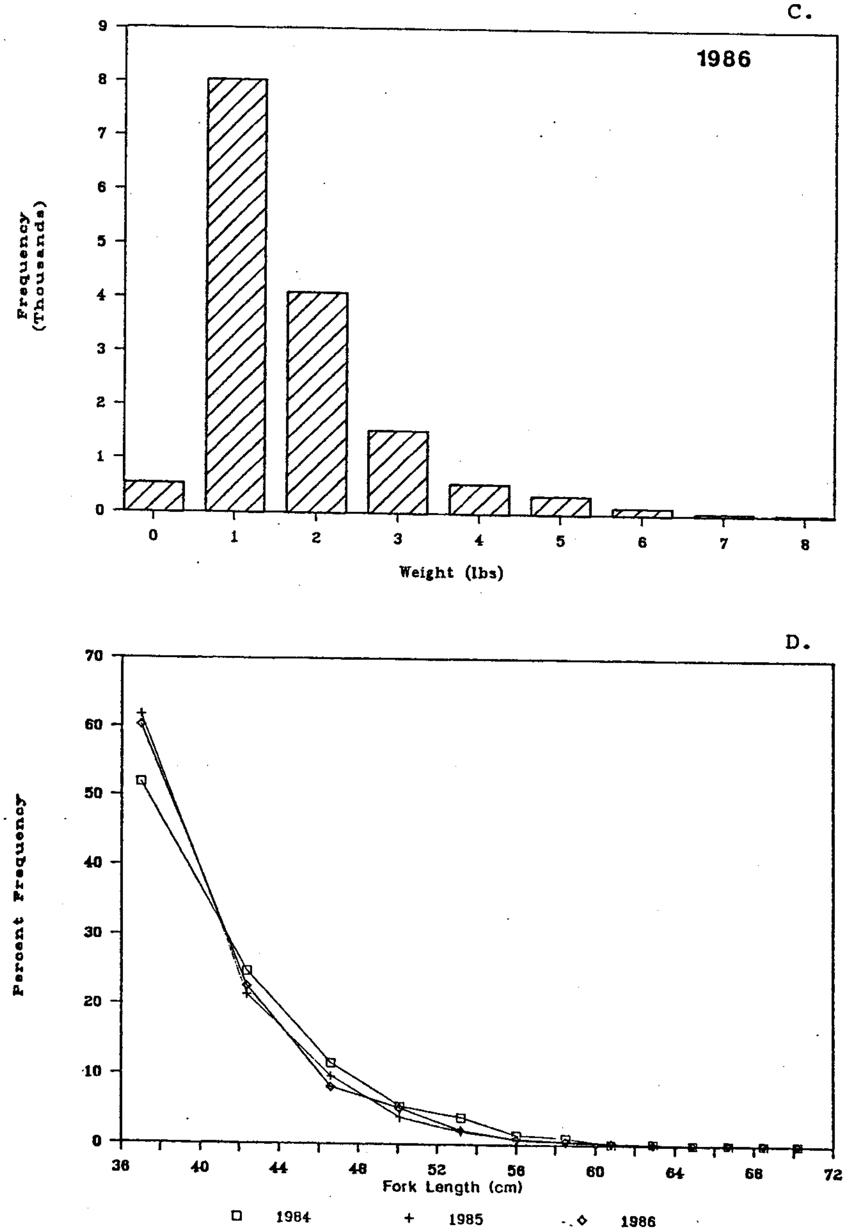


Figure 10.--Continued.

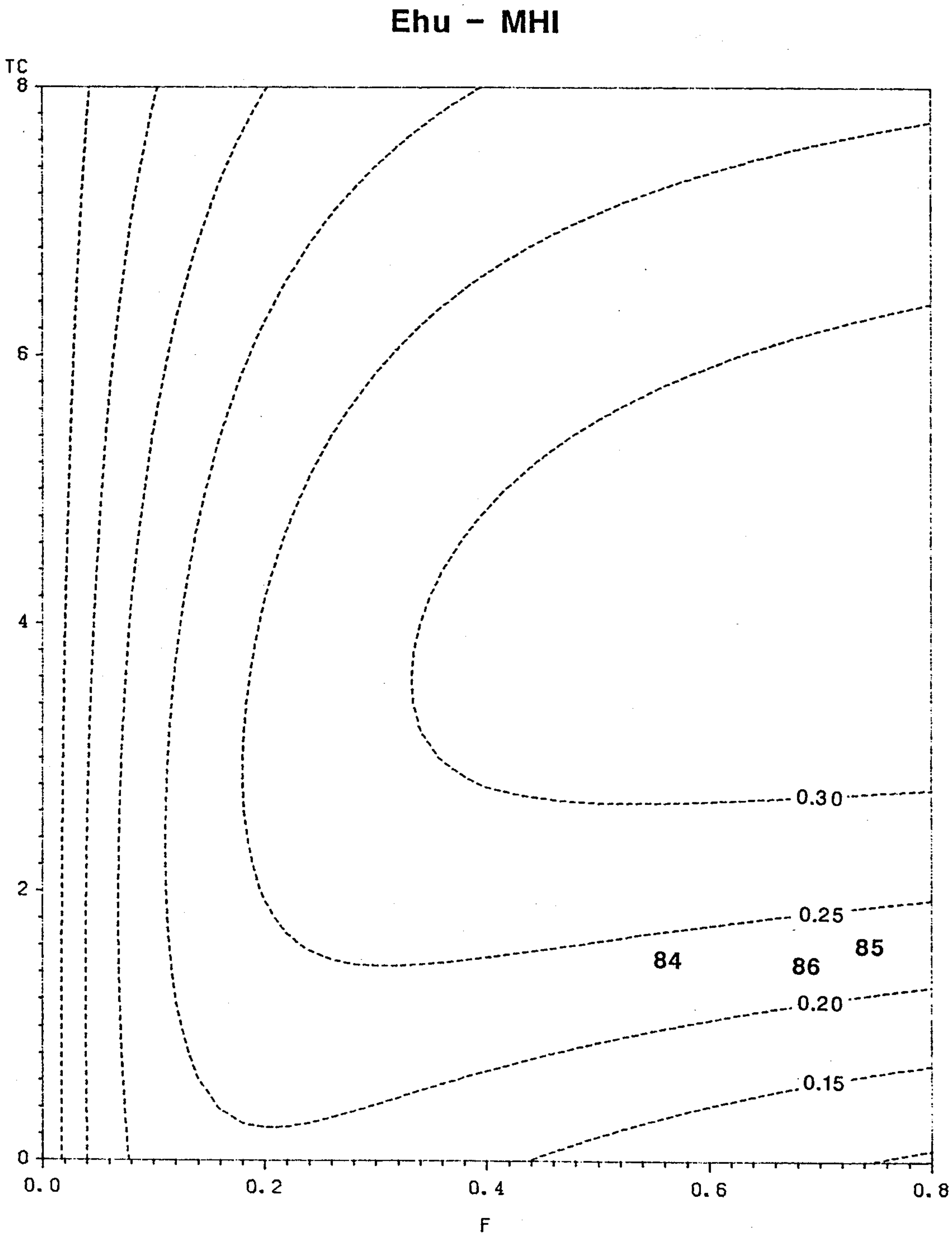


Figure 11.--Yield-per-recruit analysis for ehu caught in the main Hawaiian Islands. The unit of F is per year and the unit of t_c is years. Contoured isopleths represent the locus of points corresponding to equal yield per recruit (kg). The estimated positions of the fishery during the years 1984, 1985, and 1986 are plotted.

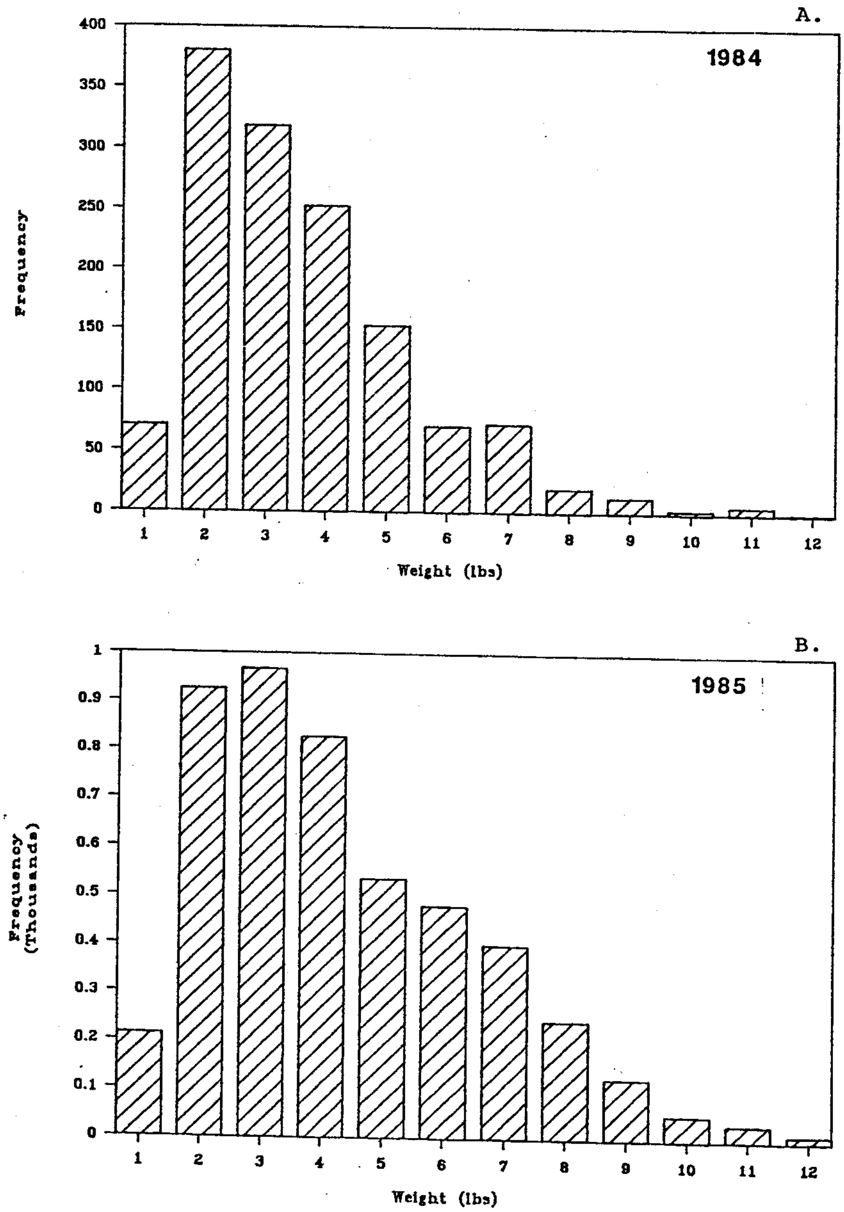
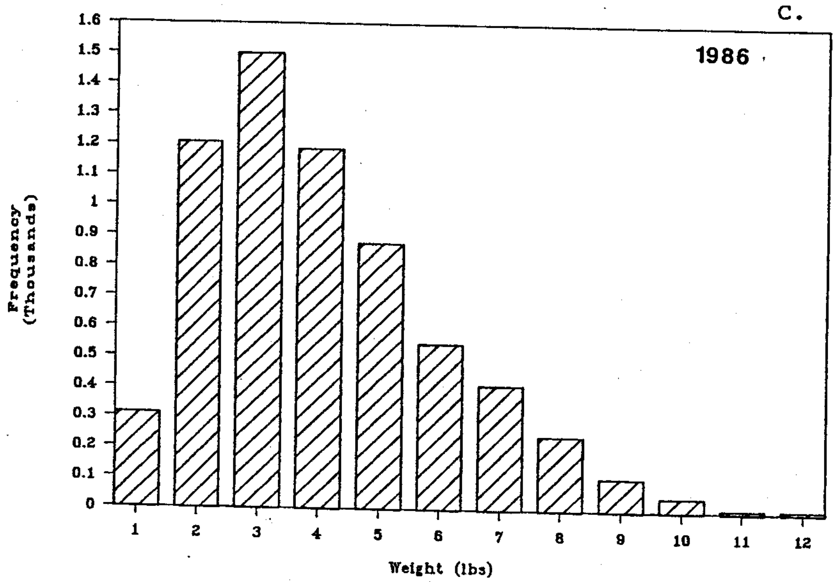


Figure 12.--Size structure of ehu landed from the Northwestern Hawaiian Islands over the period 1984-86. The first three panels (A-C) provide the weight-frequency histograms for each year. The fourth panel (D) is an overlay of the annual relative length-frequency polygons.



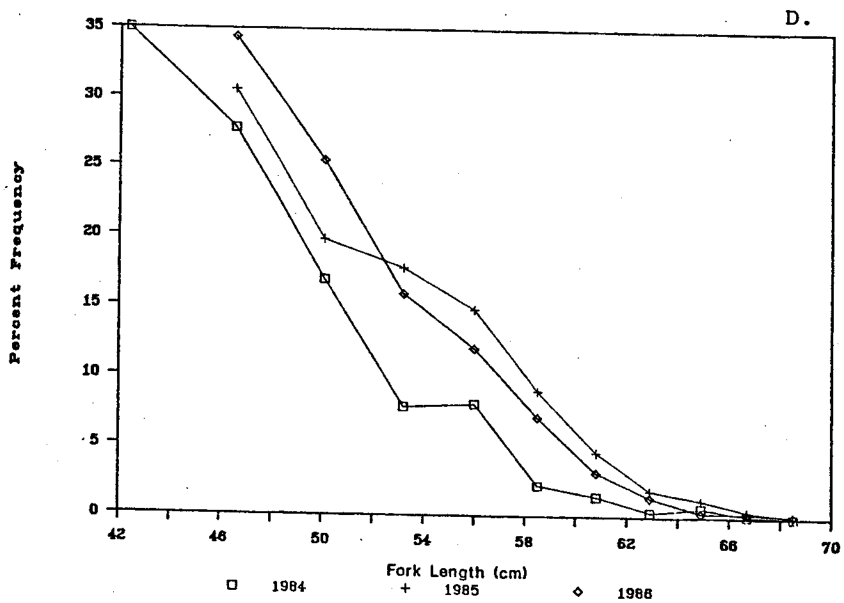


Figure 12.--Continued.

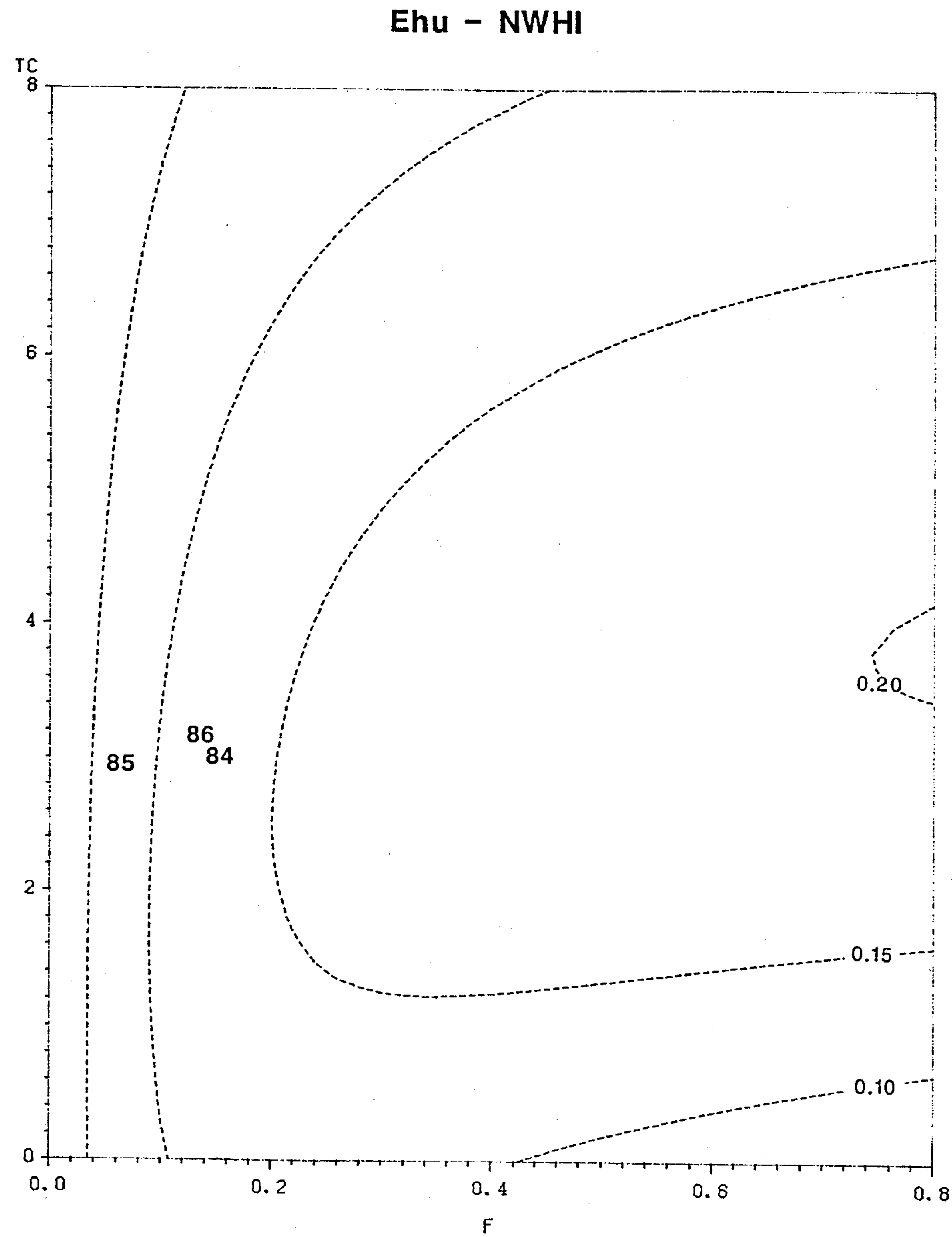


Figure 13.--Yield-per-recruit analysis for ehu caught in the Northwestern Hawaiian Islands. The unit of F is per year and the unit of t_c is years. Contoured isopleths represent the locus of points corresponding to equal yield per recruit (kg). The estimated positions of the fishery during the years 1984, 1985, and 1986 are plotted.

Main Hawaiian Islands Uku

The MHI fishery for uku stands in contrast to the other MHI fisheries discussed so far. The weight and age at entry to the fishery (Table 4) are much greater than for opakapaka, onaga, and ehu. The poor representation of small uku in the MHI catch (Fig. 14) is believed to be due to their unavailability. As indicated previously, the uku fishery generally targets fish that are aggregated for spawning, effectively conserving the pre-reproductive portion of the resource. Nonetheless, the MHI stock of uku is intensively exploited. The descending limbs of the relative length-frequency distributions for 1984-86 all demonstrate substantial curvature. Even with a much greater age at entry than the MHI fisheries already examined, the uku fishery would appear to be slightly overexploited (Fig. 15). Certainly no reduction in t_c is desirable at this time, and fishing mortality is already much greater than natural mortality (Table 4), a warning sign for snapper and grouper fisheries (Polovina 1987; Ralston 1987).

Main Hawaiian Islands Hapuupuu

The data presented in Table 4 and Figures 16 and 17 summarize the biological assessment and yield analysis for MHI hapuupuu. The weight at entry to the fishery is not great (about 1.3 kg), but neither is the estimated fishing mortality rate. In fact, the estimated position of the fishery on the isopleth surface from 1984 to 1986 places it close to the eumetric fishing line. Thus, given the prevailing level of fishing mortality, the current age at entry to the fishery (t_c) is near optimal. If fishing mortality were to increase very much, however, an increase in t_c would be desirable.

Northwestern Hawaiian Islands Hapuupuu

Hapuupuu harvested in the NWHI actually become vulnerable to fishing at a smaller size and age than do MHI conspecifics (Table 4). This is the only species to demonstrate this reversal of form. Nonetheless, as evidenced by the near linear descending limbs of the three length-frequency polygons in panel D of Figure 18, the ratio of total mortality rate to von Bertalanffy growth coefficient (Z/K) is approximately 2.0. A ratio of 2.0 is typically indicative of an unexploited grouper stock (Ralston 1979). Hence the yield-per-recruit analysis (Fig. 19) shows the NWHI stock of hapuupuu to be underutilized. If true, a moderate increase in fishing effort should produce a major increase in yield per hapuupuu recruit.

Northwestern Hawaiian Islands Butaguchi

The butaguchi is a carangid and cannot be analyzed using the methods employed up to this point. For all the species treated so far, the von Bertalanffy growth coefficient (K) and natural mortality rate (M) were estimated using the regression equations provided in Manooch (1987) and Ralston (1987). These two equations relate specifically to snappers and groupers

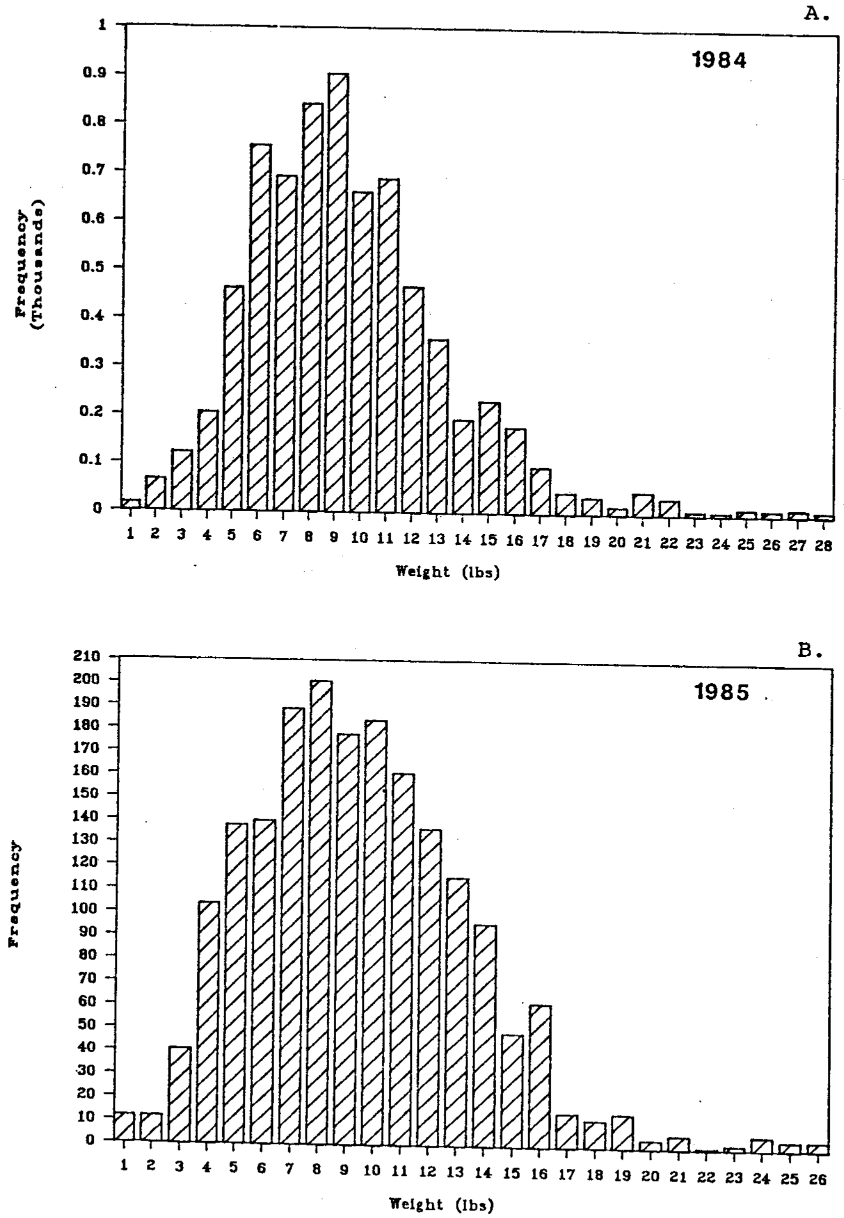


Figure 14.--Size structure of uku landed from the main Hawaiian Islands over the period 1984-86. The first three panels (A-C) provide the weight-frequency histograms for each year. The fourth panel (D) is an overlay of the annual relative length-frequency polygons.

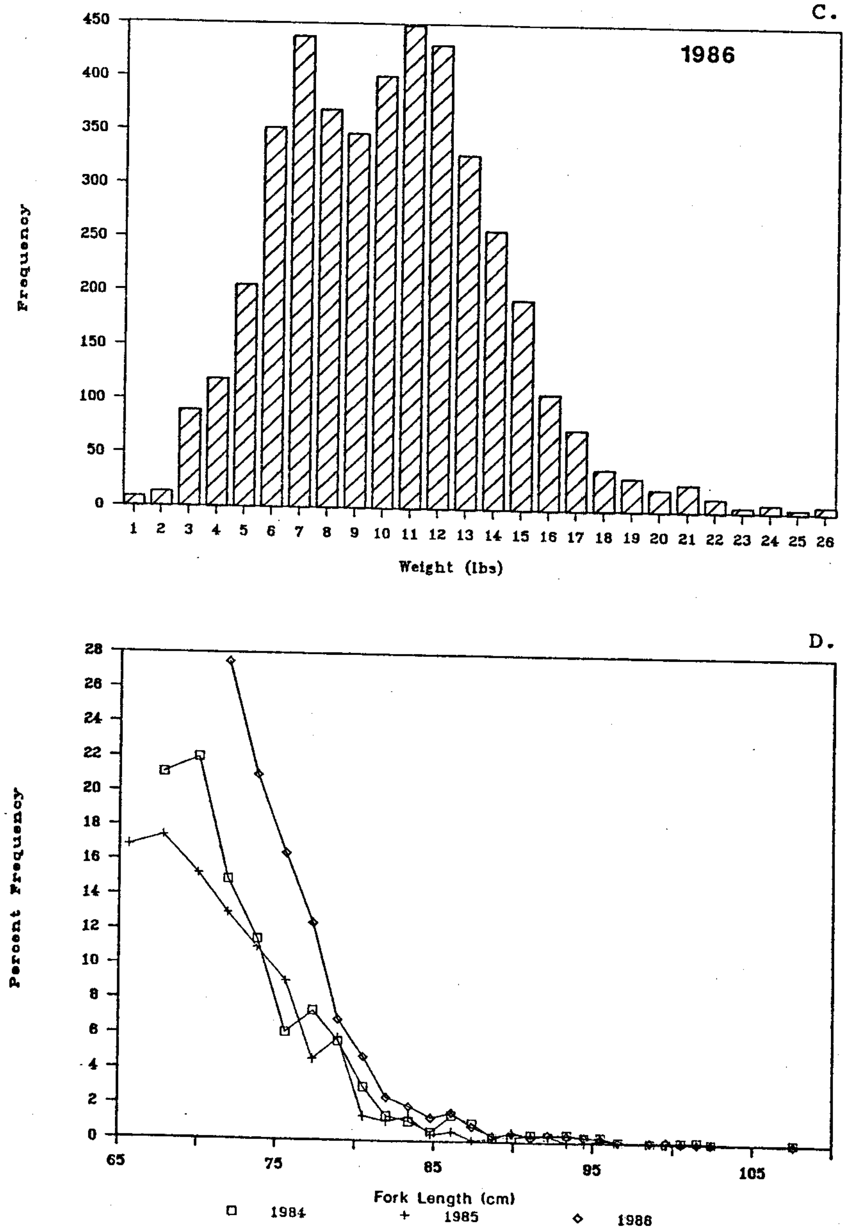


Figure 14.--Continued.

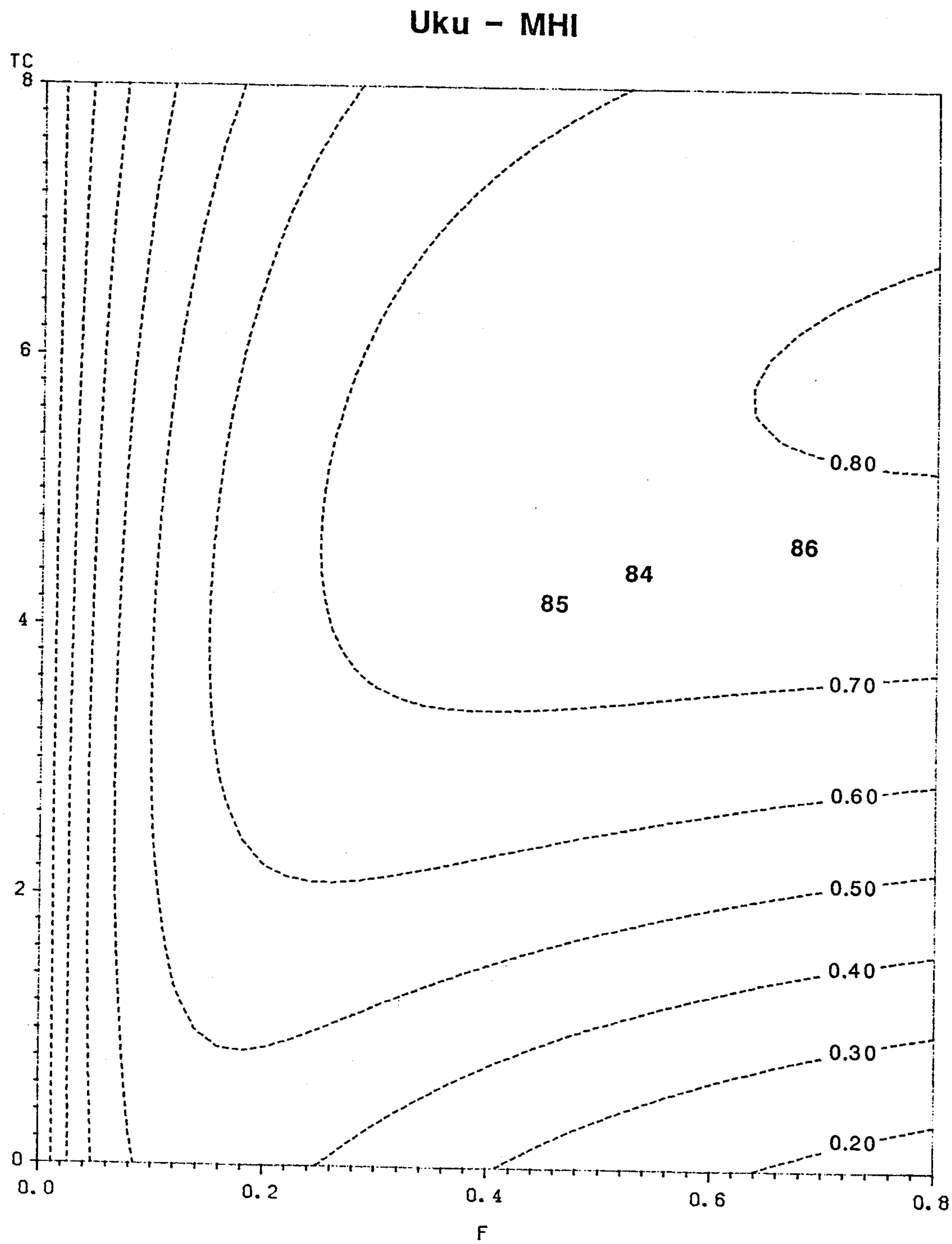


Figure 15.--Yield-per-recruit analysis for uku caught in the main Hawaiian Islands. The unit of F is per year and the unit of t_c is years. Contoured isopleths represent the locus of points corresponding to equal yield per recruit (kg). The estimated positions of the fishery during the years 1984, 1985, and 1986 are plotted.

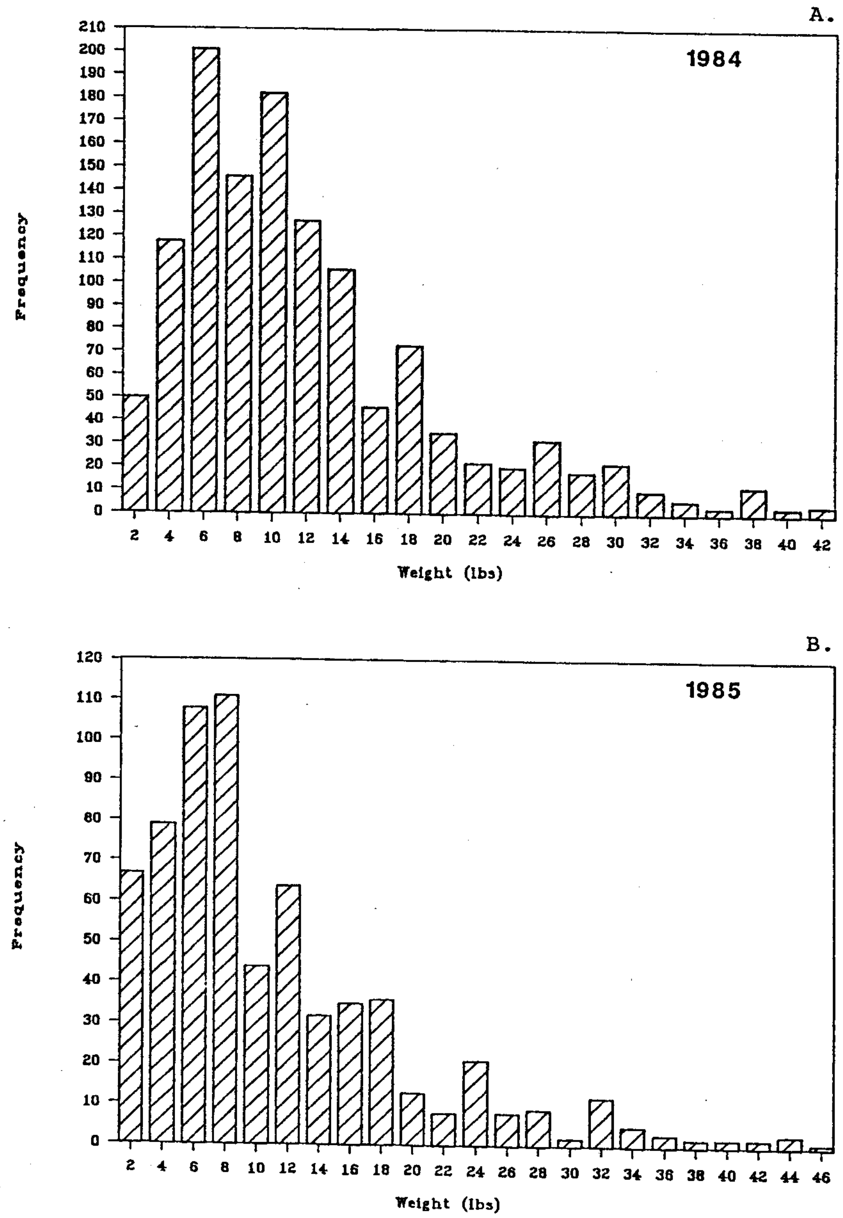
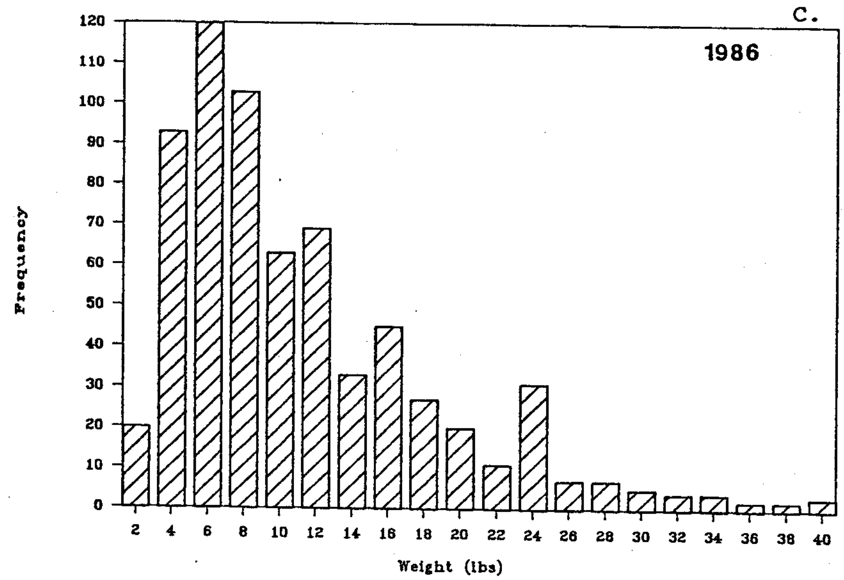


Figure 16.--Size structure of hapuupuu landed from the main Hawaiian Islands over the period 1984-86. The first three panels (A-C) provide the weight-frequency histograms for each year. The fourth panel (D) is an overlay of the annual relative length-frequency polygons.



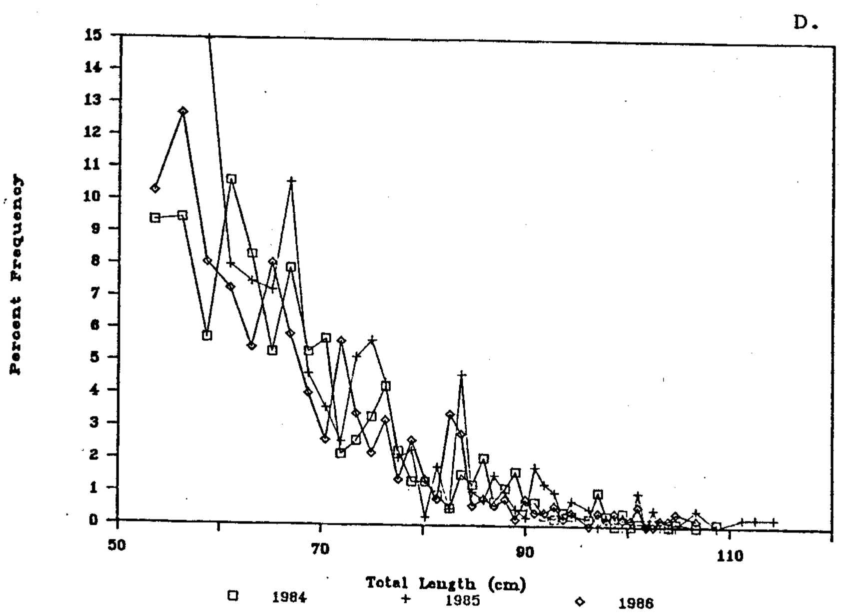


Figure 16.--Continued.

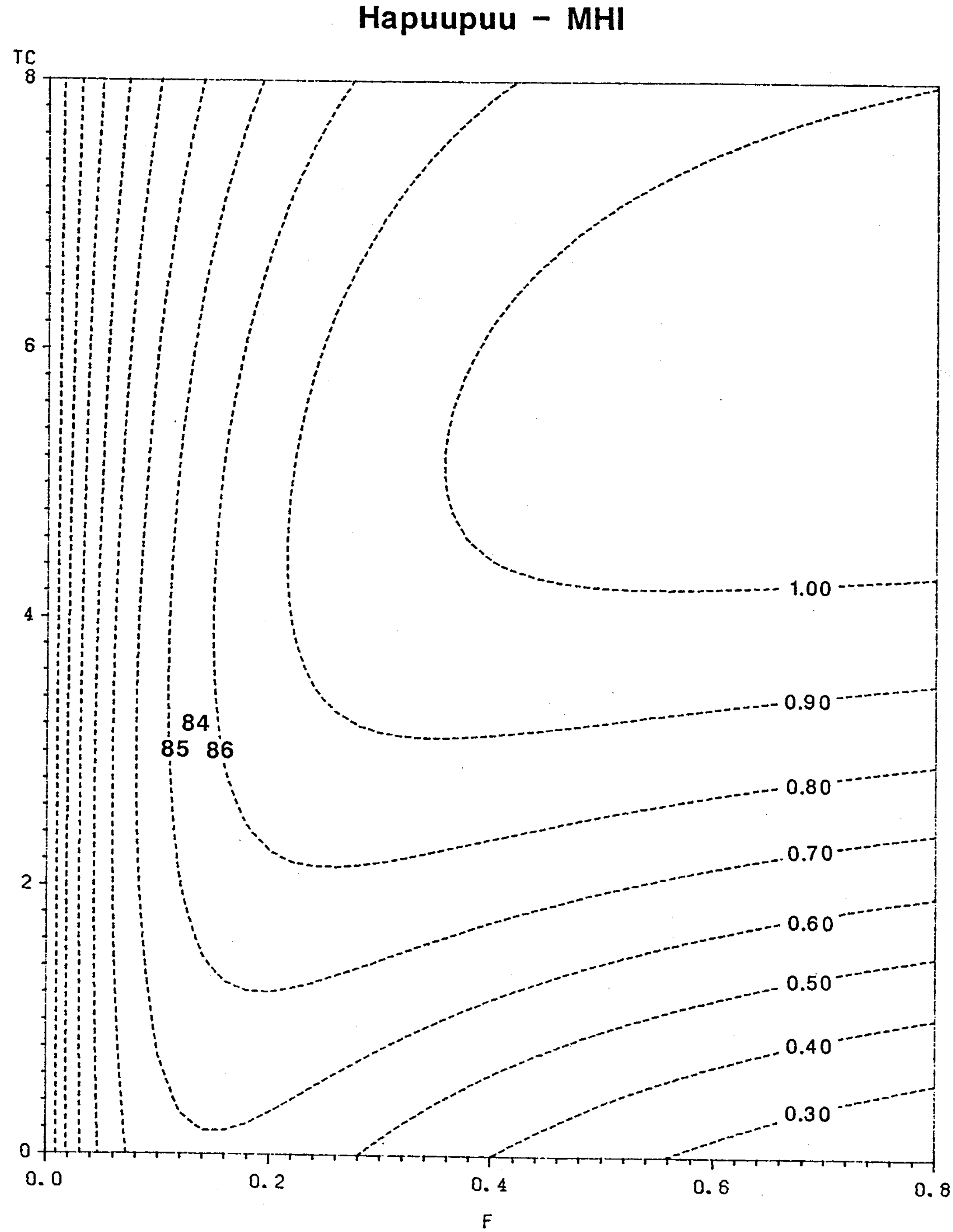
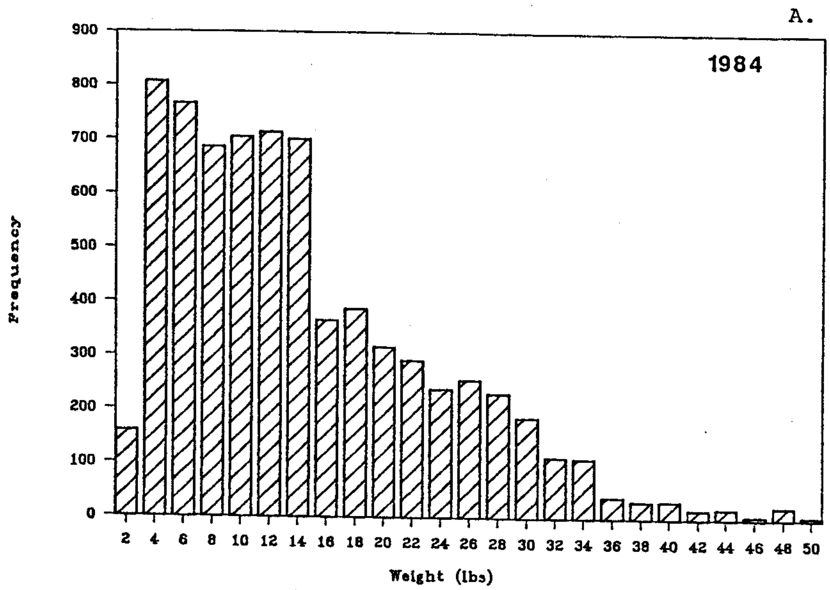


Figure 17.--Yield-per-recruit analysis for hapuupuu caught in the main Hawaiian Islands. The unit of F is per year and the unit of t_c is years. Contoured isopleths represent the locus of points corresponding to equal yield per recruit (kg). The estimated positions of the fishery during the years 1984, 1985, and 1986 are plotted.



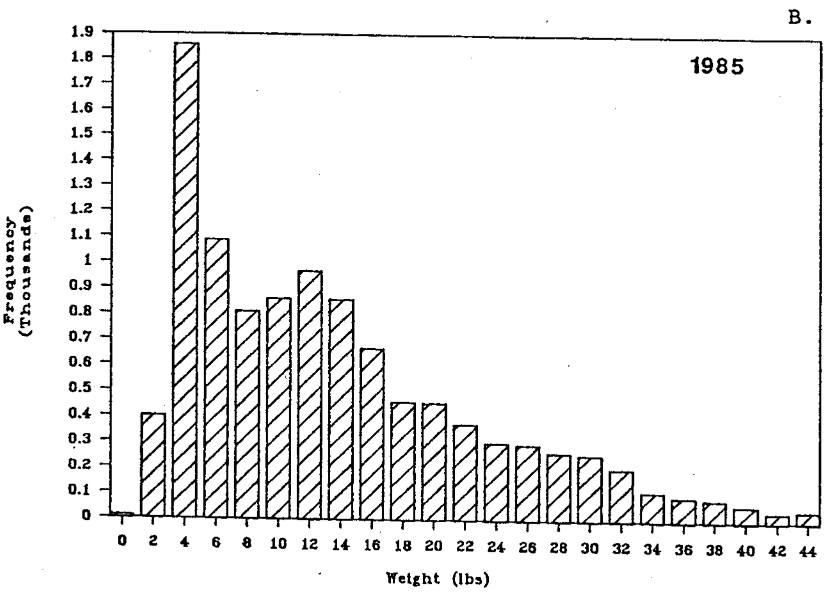
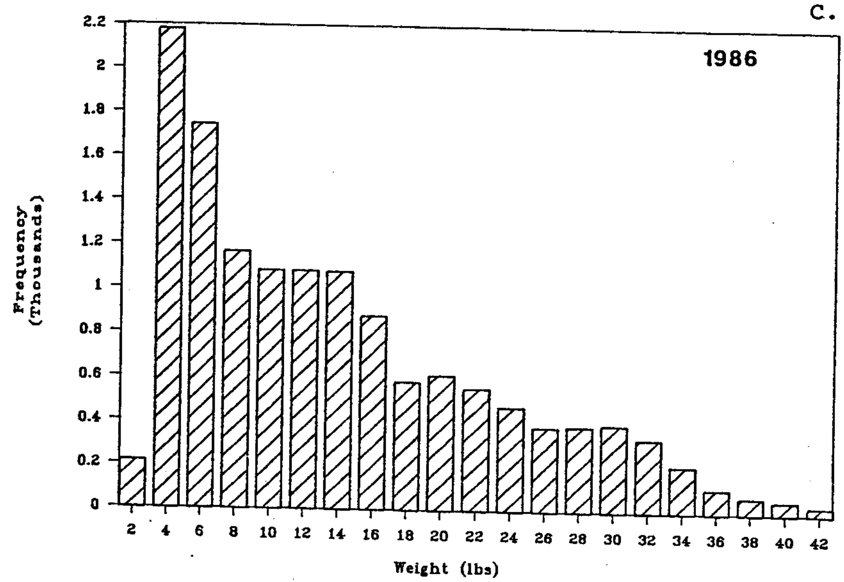


Figure 18.—Size structure of hapuupuu landed from the Northwestern Hawaiian Islands over the period 1984-86. The first three panels (A-C) provide the weight-frequency histograms for each year. The fourth panel (D) is an overlay of the annual relative length-frequency polygons.



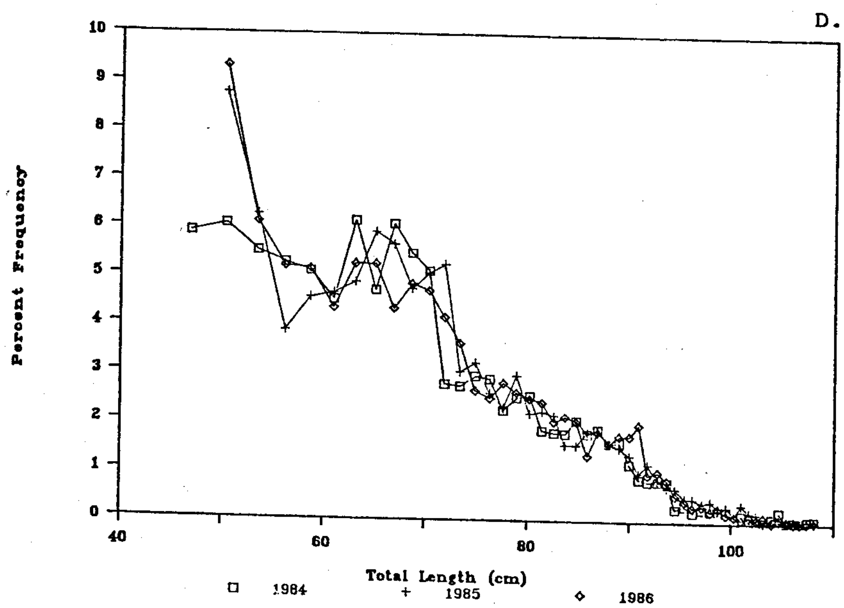


Figure 18.—Continued.

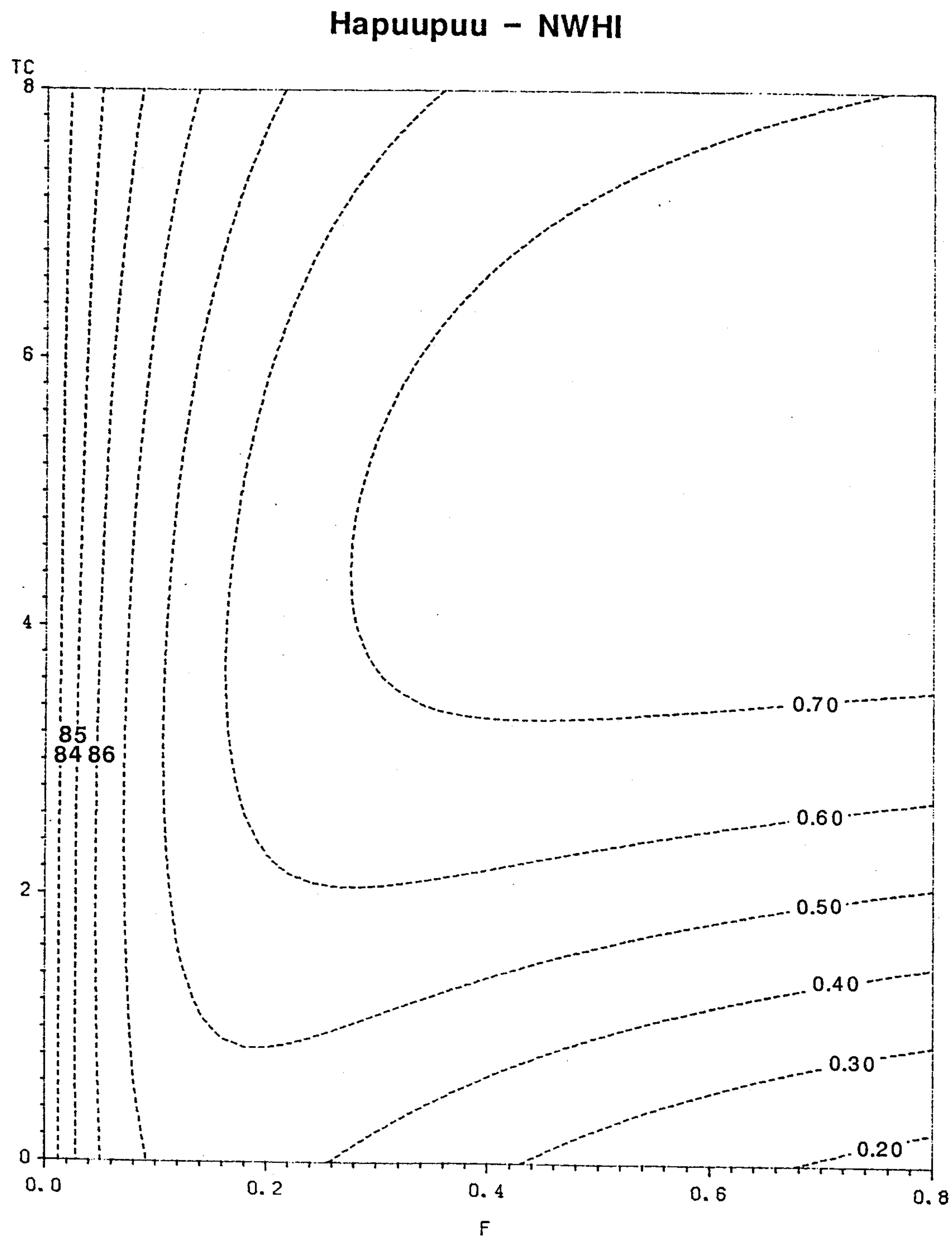


Figure 19.--Yield-per-recruit analysis for hapuupuu caught in the Northwestern Hawaiian Islands. The unit of F is per year and the unit of t_c is years. Contoured isopleths represent the locus of points corresponding to equal yield per recruit (kg). The estimated positions of the fishery during the years 1984, 1985, and 1986 are plotted.

and, without some compelling reason, it is unjustifiable to apply them to unrelated taxa. A preliminary analysis of size structure is possible, however, the results of which are presented in Table 4 and Figure 20.

Weight-frequency distributions for butaguchi landed from the NWHI are quite broad and flat (platykurtic). In such situations the detection of a mode becomes increasingly difficult and arbitrary. Still, as illustrated in the length-frequency polygons for this species (panel D), the descending limb for 1986 shows little curvature. Those for 1984 and 1985 appear to exhibit more severe levels of mortality. Like the NWHI harvest of opakapaka discussed above, this pattern is consistent with a change in the geographical pattern of fishing activity between these time periods.

Geographical Patterns of Fishing in the Northwestern Hawaiian Islands

Even though detailed information on the geographical origin of bottom fish landings did not become widely available until 1986, it is possible to examine the pattern of fishing activity in the NWHI with the existing data. Caution must be exercised, however, because only a small portion of the 1984 and 1985 NWHI bottom fish landings include bank specific fishing locations (15 and 8%, respectively).

The results presented in Figures 21 and 22 show how the geographical pattern of fishing in the NWHI has altered in the last 3 years. In Figure 21 the areal distribution of the opakapaka catch is shown in each year since 1984. Note that the fishing banks are listed horizontally and are arranged in rank order relative to distance up the archipelago. For example, Middle Bank (MD) is the closest to Honolulu, while Pearl and Hermes Reef (PH) is the most distant. The pattern is mimicked in Figure 22, in which the geographical pattern of total bottom fish landings is summarized.

The data presented in these figures strongly suggest that in 1984 and 1985 the center of bottom fishing activity in the NWHI was in the vicinity of Twin Banks, Necker Island, French Frigate Shoals, and Brooks Banks. In fact, the "expected" or average distance to the fishing grounds for a unit weight of opakapaka harvested in 1984 was 498 nmi from Honolulu (Brooks Banks). The comparable figure for 1985 was 411 nmi (Necker Island, French Frigate Shoals). Because of the sparse representation of bank specific information available for these 2 years, however, it is unlikely that this slight difference in the mean distance to the fishing grounds represents any sort of meaningful alteration in fishing activity.

In contrast, bottom fish fishing activity in 1986 had extended much farther up the Hawaiian chain. Significant landings of opakapaka and other bottom fishes were taken at Gardner Pinnacle, Raita Bank, Maro Reef, Laysan Island, Northampton Seamounts, Pioneer Bank, and especially Lisianski Island. The expected distance to the fishing grounds for a unit weight of opakapaka in 1986 was 771 nmi, equivalent to traveling as far as Maro Reef and Laysan Island.

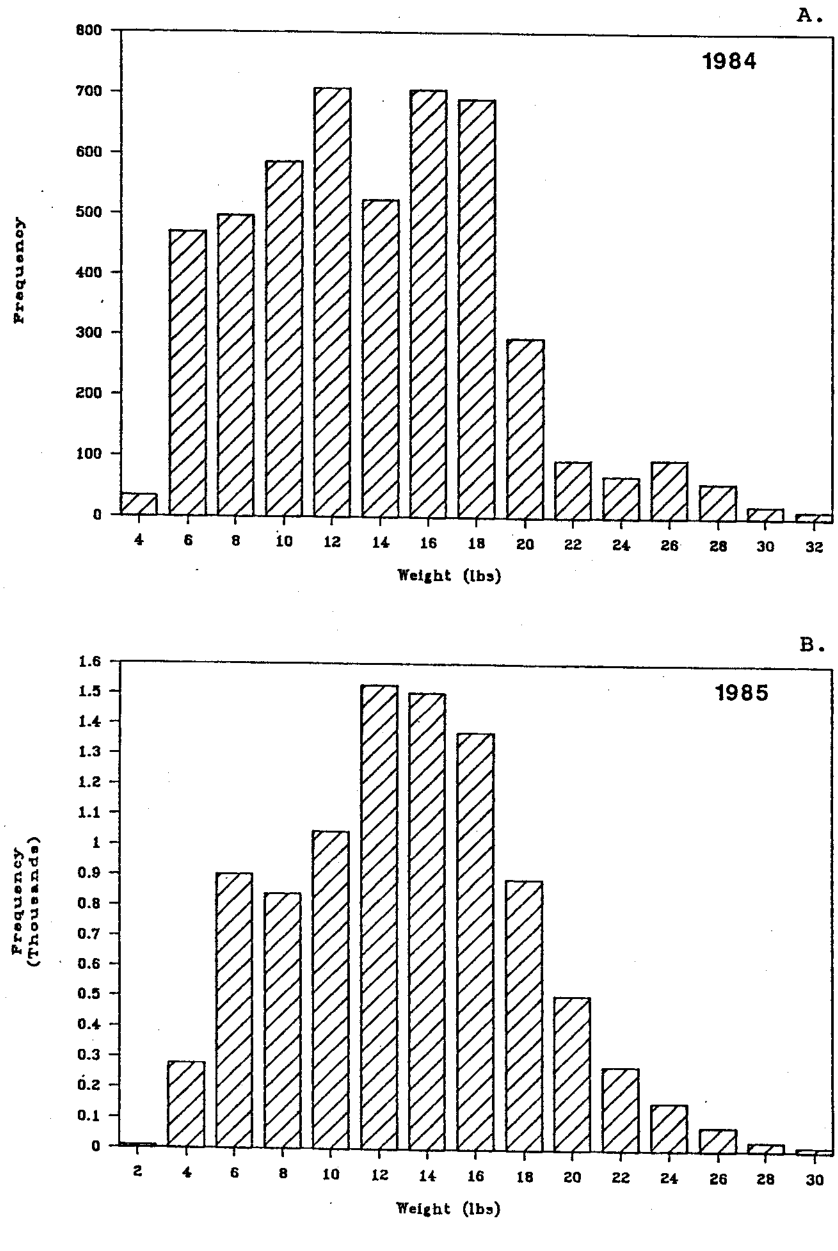
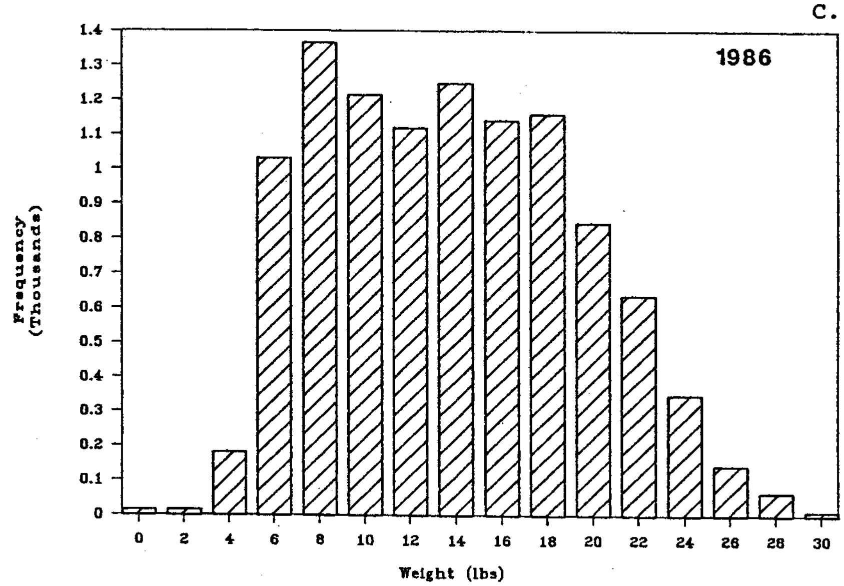


Figure 20.--Size structure of butaguchi landed from the Northwestern Hawaiian Islands over the period 1984-86. The first three panels (A-C) provide the weight-frequency histograms for each year. The fourth panel (D) is an overlay of the annual relative length-frequency polygons.



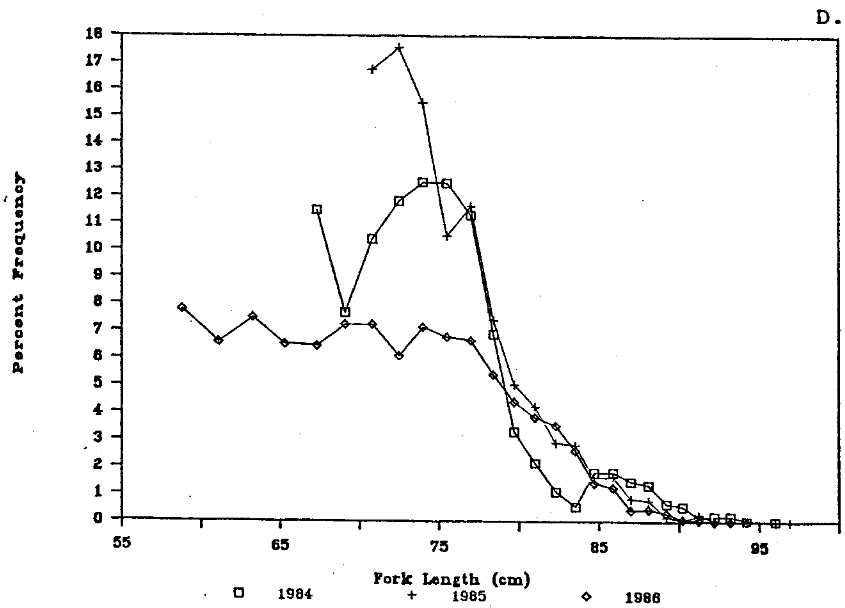


Figure 20.--Continued.

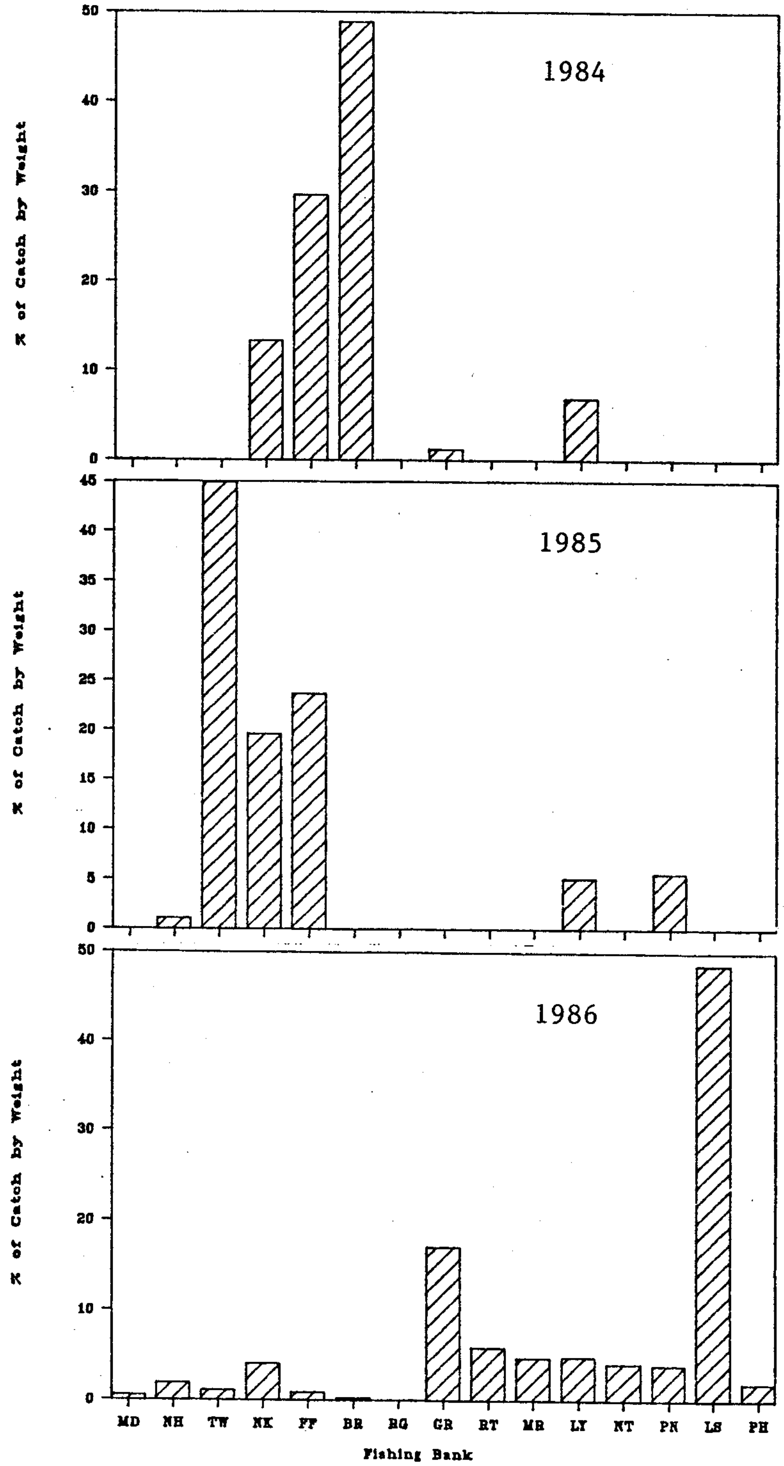


Figure 21.--Locations of opakapaka harvests in the Northwestern Hawaiian Islands (1984-86). Fishing bank abbreviations are as follows: MD = Middle Bank, NH = Nihoa, TW = Twin Banks, NK = Necker Island, FF = French Frigate Shoals, BR = Brooks Banks, RG = St. Rogatien Banks, GR = Gardner Pinnacles, RT = Raita Bank, MR = Maro Reef, LY = Laysan Island, NT = Northampton Seamounts, PN = Pioneer Bank, LS = Lisianski Island, PH = Pearl and Hermes Reef.

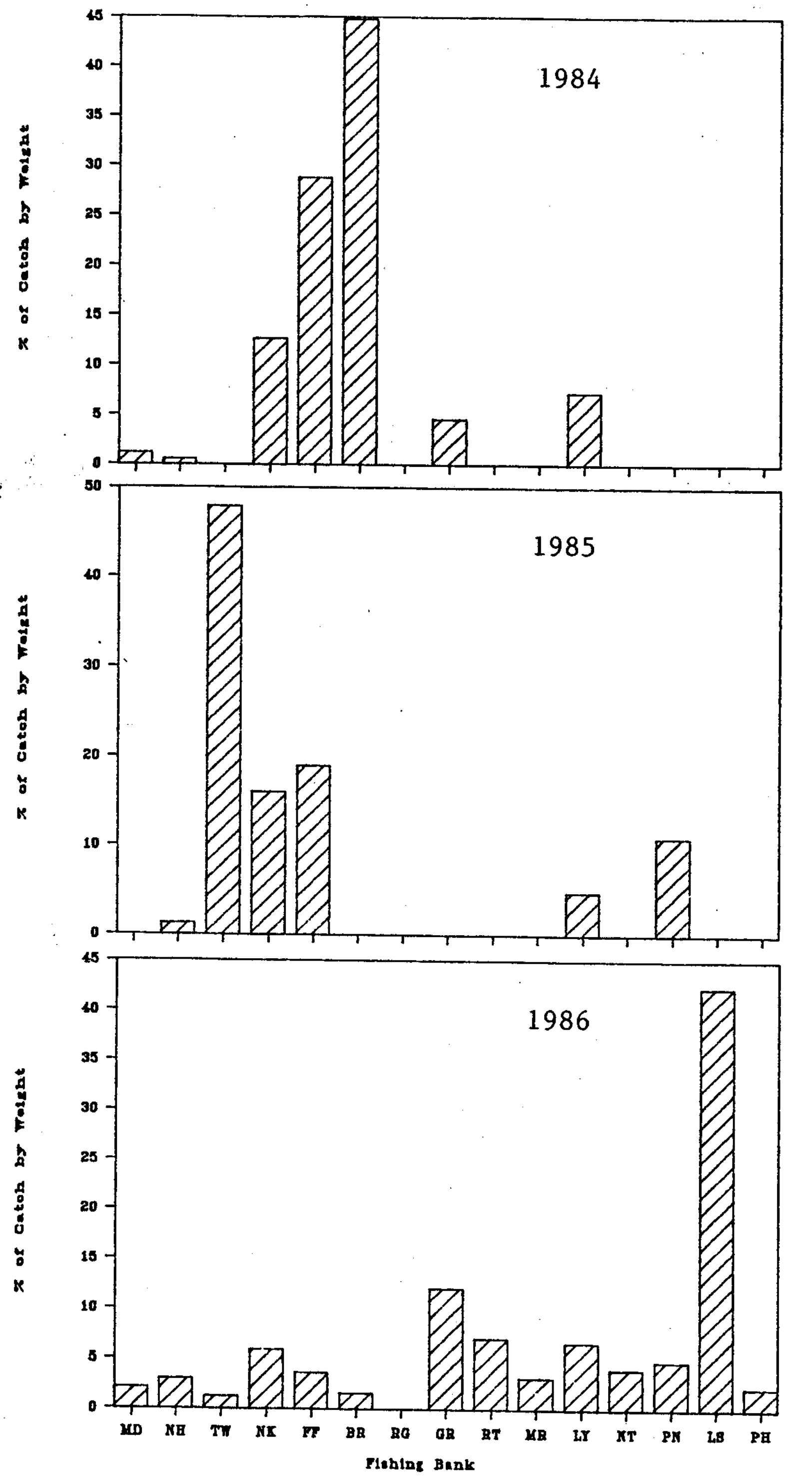


Figure 22.--Locations of bottom fish harvests in the Northwestern Hawaiian Islands (1984-86). Fishing bank abbreviations are as follows: MD = Middle Bank, NH = Nihoa, TW = Twin Banks, NK = Necker Island, FF = French Frigate Shoals, BR = Brooks Banks, RG = St. Rogatien Banks, GR = Gardner Pinnacles, RT = Raita Bank, MR = Maro Reef, LY = Laysan Island, NT = Northampton Seamounts, PN = Pioneer Bank, LS = Lisianski Island, PH = Pearl and Hermes Reef.

These results illustrate that the fishing activities of the bottom fishing fleet in the NWHI have been in a dynamic state of flux. Fishermen are traveling greater distances up the Hawaiian Island chain in order to encounter the higher catch rates that characterize unexploited fishing grounds. The move up the archipelago has occurred in conjunction with what has been an overall decline in the NWHI harvest of opakapaka, the previous mainstay of the fishery. Significantly, the natural abundance of opakapaka is known to decline with the distance traveled up the NWHI (Moffitt 1980; Humphreys 1986). The "fishing-up" process (sensu Ricker 1975) for this species in the NWHI is now likely complete.

Bottom Fishing Effort and CPUE in the Northwestern Hawaiian Islands

For the years 1984-86 there were 144, 164, and 166 recorded "bottom fishing trips" to the NWHI, respectively. Due to a small catch many of these represented an ineffective application of fishing effort, however. Thus, in order to qualify as an effective fishing trip (the nominal unit of fishing effort), at least 454 kg (1,000 lb) of bottom fish needed to be landed and marketed at the wholesale market. Under this constraint there were 108, 136, and 140 effective bottom fish fishing trips to the NWHI over the time period in question. Moreover, the mean catches (lb) of bottom fish per effective trip (CPUE) were 4,888, 5,332, and 5,539 during the 1984-86 period. From these data in isolation there is no indication of a decline in the abundance of bottom fish in the NWHI.

In order to more closely assess changes in NWHI bottom fish catch rates, the success of individual fishing vessels was followed over the last 3 years. The results presented in Table 5 document the annual CPUE statistics (mean pounds per effective fishing trip) for the 30 different vessels that actively participated in the fishery. In 1984 there were a total of 18 boats, in 1985 there were 21, and in 1986 there were 22 vessels contributing significantly to the fishery. Thus, the balance of entry to and exit from the fishery has resulted in a net gain in each year for which there are data. In terms of participants the fishery is growing.

Close examination of the data in Table 5 reveals 11 boats that fished all 3 years. Standardizing annual comparisons of CPUE by restricting the computation of sampling statistics to a uniform set of sampling units (i.e., vessels) should increase the power of the comparison to detect change. The mean catch rates of the 11 vessels that participated in the NWHI fishery during all 3 years for which there are data are 4,190, 4,230, and 4,866 lb per effective bottom fish fishing trip, respectively. Standard deviations about these means are 1,750, 1,827, and 1,886. These figures confirm the prior comparison based upon the entire fleet. Overall there has been no decline in the total bottom fish catch per NWHI fishing trip since 1984. If anything, there has been a slight increase.

Table 5.--Bottom fish CPUE in the Northwestern Hawaiian Islands. The catch rates (pounds per trip) of 30 different fishings vessels are listed for the years 1984-86. Note that 11 different vessels (H-R) fished in all 3 years.

Vessel		1984	1985	1986
1.	A	6,202	--	--
2.	B	2,554	--	--
3.	C	10,812	--	--
4.	D	2,905	--	--
5.	E	1,489	1,042	--
6.	F	1,391	2,130	--
7.	G	3,409	4,224	--
8.	H	4,585	3,040	5,100
9.	I	5,147	5,684	3,296
10.	J	4,743	3,630	3,526
11.	K	3,757	2,869	4,806
12.	L	3,175	4,354	4,091
13.	M	3,725	3,248	6,385
14.	N	2,229	5,959	5,653
15.	O	8,529	8,303	6,465
16.	P	4,143	4,398	4,402
17.	Q	1,922	1,744	1,368
18.	R	4,132	3,304	8,434
19.	S	--	2,397	1,466
20.	T	--	1,708	2,014
21.	U	--	7,242	7,706
22.	V	--	7,471	6,323
23.	W	--	8,994	11,328
24.	X	--	4,038	1,233
25.	Y	--	5,735	--
26.	Z	--	--	1,608
27.	AA	--	--	3,756
28.	BB	--	--	6,893
29.	CC	--	--	1,225
30.	DD	--	--	11,457

DISCUSSION

In attempting to synthesize the information presented here it is useful to review and reiterate the key assumptions of the analysis, of which there are five.

The first assumption is that the size structure of the bottom fish catch is adequately represented by the methods discussed in Ralston, Tagami, and Shiota (1986). Depending on the species they showed that 88.0-96.5% of all variation in bottom fish weights is attributable to differences between lots. Therefore, by calculating the mean weights of fish in auction lots, it is possible to generate a size-frequency distribution by allocating fish to the size class of their lot mean (Ralston and Kawamoto 1985). A refinement is to estimate the weight variance within lots as a function of the species, lot weight, and number of fish (Ralston, Tagami, and Shiota 1986). Fish are then allocated to size categories in accordance with lot means and variances under the normal distribution. This procedure accounts for 97.2-99.3% of the total variation in bottom fish weight. In this study allocation was made solely according to lot means. It was found that the estimation of L_∞ using the method of Wetherall et al. (in press) was sensitive to the largest size class represented in a length-frequency distribution. Mortality estimates were in turn very sensitive to values of L_∞. Because weight variance increases with a lot's weight and the number of fish comprising it, the process of allocation using both the mean and variance caused the presumptive assignment of fish to large weight categories, a result that could not be confirmed empirically. Allocation using only the mean weights is by comparison a more conservative approach to estimating L_∞. Still, the important point is that the weight distributions of the species studied here were estimated, undoubtedly with some error.

An even more important assumption is that the weight distributions derived from the catch (i.e., lot statistics) can be used as valid samples to infer something about the size structure of bottom fish populations in the wild. While evidence exists to show that hooks are capable of catching fish over a very broad range in size and that size structure is quite insensitive to alterations in gear (suggestive of constant selectivity) there are no data available to show that attack rates are independent of fish size. Intra-specific and behavioral interactions could alter the size composition of catch samples in ways we only partially understand (Allen 1963; Bannerot and Austin 1983). The interpretation of the descending limbs of length-frequency distributions relies critically on the assumption that catch samples are representative of the stock.

A third assumption is that snapper and grouper growth coefficients and natural mortality rates can be estimated with the comparative method. The graphs and equations presented in Manooch (1987) and Ralston (1987) permit the statistical prediction of "average" snapper and grouper vital rates from estimates of maximum size, but the extent to which the species studied here conform to such average expectations is unknown. However, at least one Hawaiian species (opakapaka) has been studied in some detail (Ralston and Miyamoto 1983; Ralston 1984). For this species the predictive estimates of vital rates are very similar to those determined by direct study.

An additional analytical simplification is that the Beverton and Holt (1956) length-based mortality estimator assumes that recruitment to the exploitable phase occurs at a constant uniform rate, and yet the spawning and recruitment of Hawaiian fishes is known to be seasonal (Walsh in press). Moreover, the length-frequency samples analyzed here represent an annual accumulation of fish in the catch. Ralston (in prep.) has shown, however, that the use of the Z/K length-based estimator is justified under such conditions. Pooling data from throughout the year results in an integrated average of stock size structure and obviates the bias due to seasonal recruitment.

Several important final assumptions are inherent in the formulation of the Beverton and Holt (1957) yield equation and underly the computation of yield per recruit. For one, this particular model assumes that recruitment to the exploitable phase is independent of stock size and fishing pressure. Over a fair range of stock conditions this assumption has been shown to be more or less realistic (Cushing 1973). Nevertheless, the subject of recruitment-overfishing is something that has not been seriously considered in this assessment. This topic deserves to be reviewed at some time in the future.

Moreover, application of the Beverton and Holt (1957) yield-per-recruit model presupposes that it is desirable to optimize the yield in biomass from a fish stock. Sometimes this may not be the case if, as a result of market conditions, a premium is placed on small fish. This may well be the case in the MHI fishery for ehu. It is possible to perform an assessment in which factors other than yield are optimized, although this has not been attempted here.

Lastly, the Beverton and Holt model is constructed under equilibrium conditions. Actually, there are several aspects of the present study in which this particular assumption is violated. The first relates to the computation of mortality rates from length-frequency distributions. As indicated previously, calculating vital rates based on length or age-frequency distributions from catch statistics provides a glimpse of historical conditions in the fishery (Ricker 1975). When these are altered through time, changes in size structure lag behind. Estimates of mortality derived here are, therefore, likely to be somewhat in error. Secondly, the actual composition of bottom fish populations under exploitation is in a state of flux. Strong evidence exists to show that the NWHI fleet has recently made significant changes in fishing grounds (Figs. 21 and 22). Thus, the fishery is not in equilibrium in time or space.

Given these principal assumptions, with their associated caveats, it is possible to draw several conclusions concerning the status of bottom fish stocks in the Hawaiian Islands.

The assessment in the MHI is generally consistent. Conditions seem to have been stable over the 1984-86 time period, as indicated by the uniformity in landing statistics (Table 3). There is evidence of growth-overfishing for three of the five species studied (opakapaka, ehu, and uku). An increase in the age at entry to the fishery would benefit all three species. Minimum size limits would therefore seem warranted, especially for opakapaka. The harvest of 1 and 2 lb pound individuals is a biological waste in the short run and over the long term it could ultimately affect the ability of the stock to replenish itself. Although there are certain costs in implementing minimum size regulations, including those due to the mortality of released fish and the transition losses incurred in moving from one equilibrium state to another (Huntsman and Waters 1987), they only become more severe as growth-overfishing continues unabated.

Even though there is evidence of overfishing in the MHI for three of the most important species of bottom fish, the condition of hapuupuu and onaga stocks would seem to be much better. The assessment for onaga, in particular, is surprising. As indicated in Table 3, MHI catch totals for this species are substantial. Moreover, the length-frequency polygons of panel D in Figure 6 show that a broad size range of fish are entering the marketplace. Relatively speaking, large onaga are plentiful in the MHI. There is thus some justification for encouraging further exploitation of this resource.

With respect to the best available information concerning MSY, it is difficult to evaluate the MHI fishery for bottom fish. A figure of 285 t of sustainable yield has been given for this fishery. In 1986 landings at the wholesale market were about 130 t. The difficulty here is that there exists a harvest of fish that does not appear at the wholesale market, which is presently unaccounted for. Recreational fishing and sales of MHI fish through other market channels are believed equal in magnitude to the wholesale share of the fishery. Although more data are needed before a proper assessment relative to MSY can be made, the harvest of bottom fish in the MHI is probably close to MSY, if not in excess of it.

The situation in the NWHI is more complex. Opakapaka landings are in a state of decline as vessels fish farther up the archipelago in search of productive fishing grounds. The fishery is presently in a state of disequilibrium, a problem exacerbated by inadequate data on fishing locations in 1984 and 1985.

The yield-per-recruit analysis for NWHI opakapaka indicated that fishing mortality is actually declining. Bottom fish effort statistics indicate otherwise. The number of effective vessel trips has increased from 108 to 140 in 3 years, a 30% increase. The likely explanation for the apparent decrease in opakapaka fishing mortality rate is that the fleet has moved to the northwest and cropped the final vestiges of opakapaka populations in the NWHI. Henceforth the fishery for this species will likely be based on catch rates characteristic of a stock under moderate exploitation.

As fishing pressure in the farther reaches of the NWHI has increased landings of other, less desirable, species have risen. The catch of hapuupuu and butaguchi in the NWHI has doubled since 1984. The natural abundance of these species to the northwest of Raita Bank does not decline in parallel with opakapaka (Moffitt 1980). Given the extensive fishing activity in the vicinity of Northampton Seamounts and Lisianski Island in 1986, an increasing share of these species in the catch is thus to be expected. Since new fishing grounds have been exploited this would explain the relatively low estimates of fishing mortality derived for the hapuupuu.

All evidence indicates that the onaga is starting to replace the opakapaka in the catch of NWHI bottom fishermen. Both are highly priced species that could support a fishery. Moreover, the yield-per-recruit analysis of NWHI onaga provided some justification for expanding fishing effort. An obstacle to the development of this fishery, however, is the shorter shelf life of onaga in comparison with opakapaka, a constraint that reduces the length of time vessels can stay on the fishing grounds.

In 1986 overall landings of bottom fish from the NWHI exceeded the best available estimate of MSY by 18%. In and of itself, this is not cause for alarm because the fishery is in a state of disequilibrium. The record harvest of 1986 is likely due in large part to the fishing-up of stocks as the fleet moved farther to the northwest. Nevertheless, there is every reason to be concerned about the biological condition of bottom fish stocks in the NWHI. With fishing activity so unstable the estimation and interpretation of vital rates from catch composition is severely compromised. One major improvement in our ability to monitor conditions within the fishery is the precise (i.e., bank specific) recording of fishing location. Without this type of data future assessments will be very much in jeopardy.

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